Systems Laboratory, Spring 2025

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Question 1

Which of the following best describes what it means for a function $y(t)$ to be a solution of an ODE?

Potential answers:

I:	**(wrong)**	It satisfies the ODE for at least one value of t.
II:	**(correct)**	It satisfies the ODE for all values of t in its domain.
III:	**(wrong)**	It approximately satisfies the ODE within a certain error margin.
IV:	**(wrong)**	It satisfies the ODE only at integer values of t.
V:	**(wrong)**	I do not know

Solution 1:

A function is a solution of an ODE if it satisfies the equation for all values of t within its domain. A solution must be valid throughout the considered interval.

Question 2

What additional information is needed to uniquely determine a solution of an ODE?

Potential answers:

I: **(wrong)** The function $y(t)$ itself.
II: **(correct)** An initial condition specifying the value of y at a given time.
III: **(wrong)** A boundary condition at two different points.
IV: **(wrong)** The highest-order derivative of y.
V: **(wrong)** I do not know

Solution 1:

An initial condition provides the necessary information to select a unique solution from the family of possible solutions to a differential equation. Without it, multiple solutions may exist.

Question 3

Given the ODE $\dot{y} = y$, which of the following functions is a solution?

Potential answers:

I: **(wrong)** $y(t) = t^2$
II: **(correct)** $y(t) = Ce^t$, where C is a constant.
III: **(wrong)** $y(t) = \sin t$
IV: **(wrong)** $y(t) = \frac{1}{t+1}$
V: **(wrong)** I do not know

Solution 1:

The function $y(t) = Ce^t$ satisfies the equation since its derivative is also Ce^t, matching the right-hand side of the ODE.

Question 4

Which of the following differential equations is nonlinear?

Potential answers:

I: **(correct)** $\dot{y} + 2y = 3$
II: **(correct)** $\dot{y} = y^2$
III: **(correct)** $\dot{y} = 3y + 5$
IV: **(correct)** $\dot{y} + \sin y = t$
V: **(wrong)** I do not know

Solution 1:

An equation $\dot{y} = f(y)$ is linear only if $f(y) = \alpha(t)y$.

Question 5

What is an equilibrium point of the ODE $\dot{y} = y(1 - y)$?

Potential answers:

I: **(wrong)** $y = 2$
II: **(correct)** $y = 0$ and $y = 1$
III: **(wrong)** $y = -1$
IV: **(wrong)** $y = \frac{1}{2}$
V: **(wrong)** I do not know

Solution 1:

Equilibrium points occur where $\dot{y} = 0$, meaning $y(1 - y) = 0$. This happens at $y = 0$ and $y = 1$.

Question 6

Which of the following autonomous systems is nonlinear?

Potential answers:

I: (**correct**) $\dot{y} = 3y + 5$
II: (**correct**) $\dot{y} = y^2 + 3y$
III: (**correct**) $\dot{y} = 2y - 4$
IV: (**wrong**) $\dot{y} = -0.5y$
V: (**wrong**) I do not know

Solution 1:

A differential equation is nonlinear if it includes terms such as y^2, $\sin(y)$, or e^y. The equation $\dot{y} = y^2 + 3y$ contains a quadratic term, making it nonlinear. The solutions $3y + 5$ and $2y - 4$ are affine, and thus nonlinear.

Question 7

Which of the following differential equations is autonomous?

Potential answers:

I: **(correct)** $\dot{y} = -2y + 5$
II: **(wrong)** $\dot{y} = 3y + \sin(t)$
III: **(wrong)** $\dot{y} = ty - 4$
IV: **(wrong)** $\dot{y} = e^t - y$
V: **(wrong)** I do not know

Solution 1:

A system is autonomous if its dynamics do not explicitly depend on time t. The equation $\dot{y} = -2y + 5$ only depends on y and is therefore autonomous. The other options include explicit dependence on t.

Question 8

Which of the following equations represents a time-invariant system?

Potential answers:

I: **(correct)** $\dot{y} = 4y + u$
II: **(wrong)** $\dot{y} = 2ty$
III: **(wrong)** $\dot{y} = \sin(t)y$
IV: **(wrong)** $\dot{y} = y + 3t$
V: **(wrong)** I do not know

Solution 1:

A system is time-invariant if its coefficients do not explicitly depend on time. The equation $\dot{y} = 4y + u$ meets this criterion, whereas the other options contain explicit time dependencies.

Question 9

Consider the equation $\dot{y} = -0.3y + (2t)u$. How should this system be classified?

Potential answers:

I: **(wrong)** Linear, autonomous, time-invariant
II: **(wrong)** Linear, autonomous, time-varying
III: **(correct)** Linear, non-autonomous, time-varying
IV: **(wrong)** Nonlinear, non-autonomous, time-varying
V: **(wrong)** I do not know

Solution 1:

The system is linear because it contains no nonlinear terms in y or in u. It is non-autonomous due to the explicit dependence on u, and it is time-varying since the coefficient of u depends on t.

Question 10

Which function represents a linear system?

Potential answers:

I: **(wrong)** $\dot{y} = y^3 + 2y$
II: **(correct)** $\dot{y} = 5y + 3u$
III: **(wrong)** $\dot{y} = \sin(y) + u$
IV: **(wrong)** $\dot{y} = e^y - u$
V: **(wrong)** I do not know

Solution 1:

A system is linear if it satisfies the superposition principle. The equation $\dot{y} = 5y + 3u$ is linear because it only includes first-degree terms in y and u. The other options contain nonlinear terms such as y^3, $\sin(y)$, or e^y.

Question 11

What is the mathematical definition of an equilibrium point for a dynamical system $\dot{y} = f(y, u)$?

Potential answers:

I:	**(wrong)**	A point where $f(y, u)$ is maximized
II:	**(correct)**	A point where $f(y, u) = 0$
III:	**(wrong)**	A point where y is always increasing
IV:	**(wrong)**	A point where y is always decreasing
V:	**(wrong)**	I do not know

Solution 1:

An equilibrium point is defined as a point where the system's derivative $\dot{y}$ is zero, meaning the state remains constant over time.

Question 12

Which of the following statements about equilibrium points is correct?

Potential answers:

I: **(wrong)** An equilibrium point is always stable

II: **(correct)** An equilibrium point is where the system's state does not change over time

III: **(wrong)** An equilibrium point is a location where external inputs are irrelevant

IV: **(wrong)** An equilibrium point always corresponds to $y = 0$

V: **(wrong)** I do not know

Solution 1:

An equilibrium point is defined as a state where the time derivative of the system

Question 13

Graphically, how can equilibrium points be identified for an autonomous system $\dot{y} = f(y)$?

Potential answers:

I: **(wrong)** By finding where $y = 0$

II: **(correct)** By finding the points where $f(y) = 0$ on the phase plot

III: **(wrong)** By locating the steepest points of the function $f(y)$

IV: **(wrong)** By identifying the points where y reaches its maximum or minimum values

V: **(wrong)** I do not know

Solution 1:

Equilibrium points occur where $\dot{y} = f(y) = 0$, which correspond to the intersec-

Question 14

Consider the system $\dot{T} = -0.5(T - 20)$. What is the equilibrium temperature?

Potential answers:

I: **(wrong)** $T = 0$
II: **(correct)** $T = 20$
III: **(wrong)** $T = -20$
IV: **(wrong)** $T = 40$
V: **(wrong)** I do not know

Solution 1:

Setting $\dot{T} = 0$ gives $-0.5(T - 20) = 0$, which simplifies to $T = 20$. This is the equilibrium point of the system.

Question 15

For the linear system $\dot{y} = ay + bu$, under what condition is (y_0, u_0) an equilibrium?

Potential answers:

I: **(wrong)** When $a = 0$ only

II: **(correct)** When $ay_0 + bu_0 = 0$

III: **(wrong)** When $y_0 = 0$ and $u_0 = 0$ always

IV: **(wrong)** When u_0 is arbitrary

V: **(wrong)** I do not know

Solution 1:

To find an equilibrium, set $\dot{y} = 0$, leading to $ay + bu = 0$. Solving for y_0 and u_0 gives the equilibrium condition.

Question 16

If we have an autonomous time-varying ODE, can we have equilibria?

Potential answers:

I:	**(wrong)**	No, time-variation always prevents equilibria.
II:	**(correct)**	Yes, equilibria can exist if the system allows constant solutions.
III:	**(wrong)**	Only if the system is also linear.
IV:	**(wrong)**	Yes, but only if the system is also periodic.
V:	**(wrong)**	I do not know

Solution 1:

Equilibria exist when the derivative of the state variables is zero. Even though the system is time-varying, there can still be points where the vector field is zero, leading to equilibrium. For example, we may have $\dot{y} = ty$. When $y = 0$ we have

Question 17

Can we have dynamical systems that do not have any equilibria?

Potential answers:

I: **(<u>wrong</u>)** No, every system has at least one equilibrium.
II: **(<u>correct</u>)** Yes, with no fixed points may lack equilibria.
III: **(<u>wrong</u>)** Only non-autonomous systems can lack equilibria.
IV: **(<u>wrong</u>)** No, because every system must have at least a trivial equilibrium.
V: **(<u>wrong</u>)** I do not know

Solution 1:

Very simple example: $\dot{y} = 1$.

Question 18

If we have a non-autonomous ODE, can we have equilibria if the input is always changing, e.g., $u = \sin(t)$?

Potential answers:

I:	**(wrong)**	Yes, the input does not affect equilibrium conditions.
II:	**(wrong)**	No, because a changing input continuously affects system states.
III:	**(wrong)**	Only if the input has a zero mean.
IV:	**(wrong)**	Yes, but only if the system is linear.
V:	**(correct)**	Yes, and the system does not need to be linear.
VI:	**(wrong)**	I do not know

Solution 1:

A simple example: $\dot{y} = yu$. For $y = 0$ we have for sure an equilibrium independently

Question 19

If we have a non-autonomous LTI ODE, can we have equilibria if the input is always changing, e.g., $u = \sin(t)$?

Potential answers:

I: **(wrong)** Yes, because LTI systems always have equilibria.

II: **(correct)** No, because the continuously varying input prevents a steady state.

III: **(wrong)** Only if the system has no damping.

IV: **(wrong)** Yes, but only if the input is periodic.

V: **(wrong)** I do not know

Solution 1:

For an LTI system, equilibrium requires all derivatives to be zero. A continuously

Question 20

What is the primary purpose of a phase portrait?

Potential answers:

I: **(wrong)** To find the exact numerical solution of a system
II: **(correct)** To visualize the qualitative behavior of a dynamical system
III: **(wrong)** To approximate the integral of a function
IV: **(wrong)** To determine the frequency response of a system
V: **(wrong)** I do not know

Solution 1:

A phase portrait is a graphical representation of the trajectories of a system in state space, giving insight into equilibrium points, stability, and system behavior without solving the equations explicitly.

Question 21

How do you determine equilibrium points in a phase portrait of a first-order system $\dot{y} = f(y)$?

Potential answers:

I: **(wrong)** By solving $\dot{y} = 0$ for all values of t
II: **(correct)** By solving $f(y) = 0$ for y
III: **(wrong)** By integrating $f(y)$ over time
IV: **(wrong)** By setting $f(y)$ to a constant value
V: **(wrong)** I do not know

Solution 1:

Equilibrium points are the values of y where $\dot{y} = f(y) = 0$. These are points where the system remains at rest if not perturbed.

Question 22

Which of the following best describes the phase portrait of the system $\dot{y} = y(1 - y)$?

Potential answers:

I: **(wrong)** It consists of a single trajectory with no equilibrium points

II: **(correct)** It has two equilibrium points at $y = 0$ and $y = 1$, with flow directions determined by the sign of $f(y)$

III: **(wrong)** It has infinitely many equilibrium points

IV: **(wrong)** It has no equilibrium points and exhibits oscillatory behavior

V: **(wrong)** I do not know

Solution 1:

The function $f(y) = y(1 - y)$ has two roots at $y = 0$ and $y = 1$, which are the equilibrium points. The direction of flow depends on the sign of $f(y)$.

Question 23

What distinguishes the phase portrait of a second-order system from a first-order system?

Potential answers:

I: **(wrong)** Second-order phase portraits only have one equilibrium point

II: **(correct)** Second-order phase portraits require a two-dimensional state space (e.g., x vs. $\dot{x}$)

III: **(wrong)** First-order systems can have limit cycles, while second-order systems cannot

IV: **(wrong)** Phase portraits for second-order systems do not contain information about stability

V: **(wrong)** I do not know

Solution 1:

Question 24

Which of the following statements about phase portraits of nonlinear systems is correct?

Potential answers:

I: **(wrong)** Nonlinear systems always have a single equilibrium point

II: **(wrong)** Nonlinear phase portraits can be analyzed only by solving the system numerically

III: **(correct)** Nonlinear phase portraits may exhibit equilibrium points, limit cycles, and chaotic behavior

IV: **(wrong)** Nonlinear phase portraits always resemble those of linear systems for small perturbations

V: **(wrong)** I do not know

Solution 1:

Question 25

PID control requires a model of the system to function correctly.

Potential answers:

I: **(wrong)** yes, always
II: **(correct)** no, it works without a model
III: **(wrong)** I do not know

Solution 1:

A PID controller works without requiring a model of the system. Instead, it uses feedback from the systems output to adjust the control input. The three parametersproportional (K_p), integral (K_i), and derivative (K_d)are tuned based on system behavior, but no explicit system model is necessary. This makes PID controllers simple and widely applicable, even in systems where modeling is difficult.

Question 26

Model Predictive Control (MPC) can only be applied when the model is perfect.

Potential answers:

I: **(wrong)** yes, the model must be perfect
II: **(correct)** no, it works with approximate models
III: **(wrong)** I do not know

Solution 1:

MPC does not require a perfect model, though its performance depends on how accurately the model represents the system. If the model is approximate, the controller may still work well, but the performance may degrade if the model is too far from reality. In practice, methods like robust or adaptive MPC are used to handle model inaccuracies and disturbances.

Question 27

Feedforward control is generally better than feedback control for handling disturbances.

Potential answers:

I: (**wrong**) yes, feedforward is always better
II: (**correct**) no, feedback control is better for disturbances
III: (**wrong**) I do not know

Solution 1:

Feedforward control can be effective when disturbances are predictable, as it compensates for them proactively. However, feedback control is generally better for handling unexpected disturbances or system changes because it can adjust in real-time based on the system's output. Feedback ensures that the system can respond to unmeasured or unforeseen variations, making it more robust in

Question 28

Open-loop control is more reliable than closed-loop control in all situations.

Potential answers:

I: (**wrong**) yes, open-loop is always more reliable
II: (**correct**) no, it depends on the system and application
III: (**wrong**) I do not know

Solution 1:

Open-loop control is simpler and can be more reliable in cases where the system is predictable and not subject to disturbances. However, closed-loop control is more reliable when disturbances or system variations are present, as it adjusts based on feedback. The choice between open-loop and closed-loop control depends on the specific system dynamics, complexity, and performance requirements.

Question 29

PID controllers are always preferable to MPC in terms of performance.

Potential answers:

I: **(wrong)** yes, PID always outperforms MPC
II: **(correct)** no, it depends on the system and objectives
III: **(wrong)** I do not know

Solution 1:

PID controllers are well-suited for simple systems with few inputs and outputs, especially when the system is well-understood and not subject to significant disturbances. However, MPC can be more powerful in handling complex, multivariable systems with constraints. MPC is capable of optimizing system behavior over a time horizon, making it suitable for systems where PID controllers might not be

Question 30

What does the **P** term in a PID controller stand for, and what is its primary effect?

Potential answers:

I: **(wrong)** Predictive - anticipates future errors based on current trends
II: **(correct)** Proportional - produces an output proportional to the current error
III: **(wrong)** Periodic - adjusts the control action at regular intervals
IV: **(wrong)** Passive - maintains system stability without active correction
V: **(wrong)** I do not know

Solution 1:

The **P** stands for Proportional. The proportional term produces an output value that is proportional to the current error value. The proportional response can

Question 31

What is the primary consequence of setting the **integral term (I)** too high in a PID controller?

Potential answers:

I:	**(wrong)**	The system becomes sluggish and unresponsive
II:	**(wrong)**	The system oscillates at a constant amplitude
III:	**(correct)**	The system exhibits large overshoot and becomes unstable
IV:	**(wrong)**	The system ignores steady-state errors
V:	**(wrong)**	I do not know

Solution 1:

An excessively high integral gain leads to aggressive correction of accumulated past errors, which typically causes large overshoot and system instability. The

Question 32

What does the **D** term in a PID controller primarily respond to?

Potential answers:

I: **(wrong)** The total accumulated error over time
II: **(wrong)** The absolute value of the current error
III: **(correct)** The rate of change of the error
IV: **(wrong)** The desired setpoint value
V: **(wrong)** I do not know

Solution 1:

The **D** stands for Derivative. The derivative term is concerned with the rate of change of the error with respect to time. A derivative term slows the rate of change of the controller output, which helps to reduce overshoot and improve

Question 33

What is the likely result of setting **all PID gains to zero**?

Potential answers:

I: **(correct)** The controller will take no corrective action
II: **(wrong)** The system will achieve perfect control instantly
III: **(wrong)** The system will oscillate at its natural frequency
IV: **(wrong)** The controller will use default conservative values
V: **(wrong)** I do not know

Solution 1:

Setting all PID gains (Kp, Ki, and Kd) to zero means the controller will generate no corrective output regardless of the error. The system will be completely uncontrolled, with the process variable potentially drifting away from the setpoint.

Question 34

What is the main purpose of the **integral term** in a PID controller?

Potential answers:

I: **(wrong)** To speed up the initial response to large errors
II: **(wrong)** To predict future errors based on current trends
III: **(correct)** To eliminate steady-state error
IV: **(wrong)** To filter out high-frequency noise
V: **(wrong)** I do not know

Solution 1:

The integral term's primary purpose is to eliminate steady-state error, which is the residual error that remains after the proportional term has done its work. It does this by integrating (summing) past errors over time and applying a correction

Question 35

What does it mean to linearize a nonlinear ordinary differential equation (ODE)?

Potential answers:

I: **(correct)** It means approximating the nonlinear ODE with a linear model around an equilibrium point.
II: **(wrong)** It means replacing the ODE with a completely unrelated linear system.
III: **(wrong)** It means integrating the ODE analytically to find a closed-form solution.
IV: **(wrong)** It means ignoring all nonlinear terms in the system dynamics.
V: **(wrong)** I do not know

Solution 1:

Question 36

What is the primary requirement for performing a valid linearization of a function?

Potential answers:

- I: **(wrong)** The function must be polynomial.
- II: **(correct)** The function must be differentiable at the point of linearization.
- III: **(wrong)** The function must be bounded over the entire real line.
- IV: **(wrong)** The function must have a second derivative at all points.
- V: **(wrong)** I do not know

Solution 1:

A function must be differentiable at the point of linearization to compute its first-order Taylor series expansion, which is the basis for linearization.

Question 37

Why do we typically linearize a nonlinear system around an equilibrium point?

Potential answers:

- I: **(wrong)** Because equilibrium points always yield globally valid linear models.
- II: **(wrong)** Because nonlinear systems have no real solutions.
- III: **(correct)** Because an equilibrium point ensures the validity of the local linear approximation.
- IV: **(wrong)** Because linearization eliminates all system dynamics.
- V: **(wrong)** I do not know

Solution 1:

Linearizing around an equilibrium point ensures that the approximation is mean-

Question 38

In a state-space representation of an ODE, what do the matrices A and B represent in the linearized system?

Potential answers:

I: **(<u>wrong</u>)** A and B are arbitrary matrices chosen for stability.

II: **(<u>wrong</u>)** A represents the second derivative of the state, and B represents the system's damping.

III: **(<u>wrong</u>)** A and B are obtained by solving the system for eigenvalues and eigenvectors.

IV: **(<u>correct</u>)** A is the Jacobian of the system dynamics with respect to the state, and B is the Jacobian with respect to the input.

V: **(<u>wrong</u>)** I do not know

Solution 1:

Question 39

Which of the following is a common limitation of linearizing a nonlinear system?

Potential answers:

I: **(correct)** The linearized model is only valid in a small neighborhood around the linearization point.
II: **(wrong)** The linearized model has no practical applications in control.
III: **(wrong)** Linearization makes the system unstable.
IV: **(wrong)** Linearization eliminates all dynamic behavior of the system.
V: **(wrong)** I do not know

Solution 1:

A linearized model is typically valid only in a small neighborhood around the equilibrium point where it was derived. If the system deviates significantly from

Question 40

When linearizing a nonlinear ODE around an equilibrium point, which of the following conditions ensures that the approximation improves over time?

Potential answers:

- I: **(wrong)** The equilibrium point is unstable.
- II: **(correct)** The equilibrium point is asymptotically stable.
- III: **(wrong)** The ODE has a high curvature near the equilibrium point.
- IV: **(wrong)** The initial point is far from the equilibrium.
- V: **(wrong)** I do not know.

Solution 1:

The approximation improves over time when the equilibrium point is asymptotically stable. This is because trajectories near such equilibria converge toward the

Question 41

In which of the following cases is it NOT meaningful to linearize a nonlinear ODE?

Potential answers:

I: **(wrong)** The ODE has multiple equilibrium points.
II: **(correct)** The ODE does not have any equilibrium points.
III: **(wrong)** The ODE has a small basin of attraction.
IV: **(wrong)** The ODE is highly nonlinear.
V: **(wrong)** I do not know.

Solution 1:

Linearization is not meaningful when the ODE does not have any equilibrium points, as the process of linearization relies on approximating the system near an equilibrium.

Question 42

Which of the following factors limits the validity of a linearized ODE approximation?

Potential answers:

I: **(wrong)** The linearized system has a stable equilibrium.
II: **(correct)** The basin of attraction of the equilibrium is very small.
III: **(wrong)** The ODE is continuous and differentiable.
IV: **(wrong)** The initial point is close to the equilibrium.
V: **(wrong)** I do not know.

Solution 1:

A very small basin of attraction limits the validity of the linearized approximation, as the region where the approximation holds becomes very restricted.

Question 43

What happens to the accuracy of a linearized ODE approximation near an unstable equilibrium point over time?

Potential answers:

I: **(correct)** The approximation degrades over time.
II: **(wrong)** The approximation improves over time.
III: **(wrong)** The accuracy remains constant.
IV: **(wrong)** The accuracy depends on the curvature of the ODE.
V: **(wrong)** I do not know.

Solution 1:

Near an unstable equilibrium, the approximation degrades over time because trajectories diverge from the equilibrium, making the linearized model less accurate.

Question 44

Which of the following statements about linearization is true?

Potential answers:

I: **(wrong)** Linearization is always a good approximation for any nonlinear ODE.

II: **(correct)** Linearization provides a better approximation when the initial point is closer to the equilibrium.

III: **(wrong)** Linearization is only valid for ODEs with high curvature.

IV: **(wrong)** Linearization cannot be applied to stable systems.

V: **(wrong)** I do not know.

Solution 1:

Linearization provides a better approximation when the initial point is closer to

Question 45

What does the superposition principle imply for LTI systems?

Potential answers:

I: **(wrong)** The total response is the product of the free evolution and forced response.

II: **(correct)** The total response is the sum of the free evolution and forced response.

III: **(wrong)** The total response is independent of the initial conditions.

IV: **(wrong)** The total response is only determined by the input.

V: **(wrong)** I do not know.

Solution 1:

The superposition principle implies that the total response of an LTI system is

Question 46

Which of the following is a necessary condition for the superposition principle to hold in a system?

Potential answers:

I: **(wrong)** The system must be nonlinear.
II: **(correct)** The system must be linear and time-invariant.
III: **(wrong)** The system must have time-varying parameters.
IV: **(wrong)** The system must be unstable.
V: **(wrong)** I do not know.

Solution 1:

The superposition principle holds only for Linear Time-Invariant (LTI) systems. Nonlinear or time-varying systems do not satisfy the superposition principle.

Question 47

What is the free evolution of an LTI system?

Potential answers:

I: **(wrong)** The response of the system to a nonzero input with zero initial conditions.

II: **(correct)** The response of the system to zero input with nonzero initial conditions.

III: **(wrong)** The steady-state response of the system.

IV: **(wrong)** The transient response of the system.

V: **(wrong)** I do not know.

Solution 1:

The free evolution of an LTI system is the response of the system when the input

Question 48

If an LTI system has an input $u(t) = \alpha' u'(t) + \alpha'' u''(t)$ and initial conditions $y(0) = \alpha' y'(0) + \alpha'' y''(0)$, what is the total response $y(t)$?

Potential answers:

I: **(wrong)** $y(t) = \alpha' y'(t) \cdot \alpha'' y''(t)$
II: **(correct)** $y(t) = \alpha' y'(t) + \alpha'' y''(t)$
III: **(wrong)** $y(t) = \alpha' y'(t) - \alpha'' y''(t)$
IV: **(wrong)** $y(t) = \alpha' y'(t) / \alpha'' y''(t)$
V: **(wrong)** I do not know.

Solution 1:

For an LTI system, the total response $y(t)$ is the linear combination of the individual responses $y'(t)$ and $y''(t)$, scaled by α' and α'', respectively. This is

Question 49

What is the forced response of an LTI system?

Potential answers:

- I: **(correct)** The response of the system to a nonzero input with zero initial conditions.
- II: **(wrong)** The response of the system to zero input with nonzero initial conditions.
- III: **(wrong)** The response of the system to a step input.
- IV: **(wrong)** The response of the system to a sinusoidal input.
- V: **(wrong)** I do not know.

Solution 1:

The forced response of an LTI system is the response of the system when the

Question 50

What is the impulse response of an LTI system?

Potential answers:

I: **(wrong)** The output of the system when the input is a sinusoidal function.
II: **(wrong)** The output of the system when the input is a ramp function.
III: **(wrong)** The output of the system when the input is a step function.
IV: **(correct)** The output of the system when the input is a Dirac delta function.
V: **(wrong)** I do not know.

Solution 1:

The impulse response of an LTI system is the output of the system when the input is a Dirac delta function. This response characterizes the system's behavior

Question 51

Why is the impulse response meaningful only for LTI systems?

Potential answers:

I: **(correct)** Because the impulse response is a direct consequence of the superposition principle, which applies only to LTI systems.
II: **(wrong)** Because nonlinear systems do not respond to impulses.
III: **(wrong)** Because the impulse response is too complex to compute for nonlinear systems.
IV: **(wrong)** Because nonlinear systems have infinite impulse responses.
V: **(wrong)** I do not know.

Solution 1:

The impulse response is meaningful only for LTI systems because it relies on the

Question 52

What happens to the mass-spring-damper system when the input force is a Dirac delta function?

Potential answers:

I: **(wrong)** The mass oscillates indefinitely without damping.
II: **(correct)** The mass exhibits a transient response that decays over time due to damping.
III: **(wrong)** The mass remains stationary because the impulse is too short to affect it.
IV: **(wrong)** The mass moves with constant velocity.
V: **(wrong)** I do not know.

Solution 1:

Question 53

What is the integral of $f(\tau)\delta(\tau-4)$ from $-\infty$ to $+\infty$?

Potential answers:

I: **(<u>wrong</u>)** $\int_{-\infty}^{+\infty} f(\tau)d\tau$
II: **(<u>wrong</u>)** 0
III: **(<u>correct</u>)** $f(4)$
IV: **(<u>wrong</u>)** $\delta(4)$
V: **(<u>wrong</u>)** I do not know.

Solution 1:

The integral of $f(\tau)\delta(\tau-4)$ from $-\infty$ to $+\infty$ is $f(4)$. This is because the Dirac delta function "samples" the function $f(\tau)$ at $\tau = 4$.

Question 54

What does the convolution integral $y_{\text{forced}}(t) = \int_{-\infty}^{+\infty} h(\tau)u(t-\tau)d\tau$ represent in the context of LTI systems?

Potential answers:

I: **(<u>wrong</u>)** The free evolution of the system output.
II: **(<u>correct</u>)** The forced response of the system output due to the input $u(t)$.
III: **(<u>wrong</u>)** The total response of the system, including initial conditions.
IV: **(<u>wrong</u>)** The impulse response of the system.
V: **(<u>wrong</u>)** I do not know.

Solution 1:

The convolution integral $y_{\text{forced}}(t) = \int_{-\infty}^{+\infty} h(\tau)u(t-\tau)d\tau$ represents the forced

Question 55

Which of the following is true about the convolution operation $h * u(t)$?

Potential answers:

I: **(wrong)** It is only defined for periodic signals.
II: **(wrong)** It is only applicable to discrete-time systems.
III: **(correct)** It is commutative, i.e., $h * u(t) = u * h(t)$.
IV: **(wrong)** It requires both signals to be symmetric.
V: **(wrong)** I do not know.

Solution 1:

The convolution operation is commutative, meaning $h * u(t) = u * h(t)$. This property holds for continuous-time signals in LTI systems.

Question 56

What does the impulse response $h(t)$ of an LTI system represent?

Potential answers:

I: **(wrong)** The input signal $u(t)$ applied to the system.
II: **(wrong)** The free evolution of the system output.
III: **(wrong)** The total response of the system, including initial conditions.
IV: **(correct)** The output of the system when the input is a Dirac delta function $\delta(t)$.
V: **(wrong)** I do not know.

Solution 1:

The impulse response $h(t)$ represents the output of the system when the input is a Dirac delta function $\delta(t)$. It characterizes the system's behavior.

Question 57

If $h(\tau) = 0$ for $\tau < 0$ and $u(t) = 0$ for $t < 0$, how can the convolution integral $y(t) = \int_{-\infty}^{+\infty} h(\tau)u(t-\tau)d\tau$ be simplified?

Potential answers:

I: **(correct)** $y(t) = \int_{0}^{t} h(\tau)u(t-\tau)d\tau$

II: **(wrong)** $y(t) = \int_{0}^{+\infty} h(\tau)u(t-\tau)d\tau$

III: **(wrong)** $y(t) = \int_{-\infty}^{+\infty} h(\tau)u(\tau)d\tau$

IV: **(wrong)** $y(t) = \int_{-\infty}^{0} h(\tau)u(t-\tau)d\tau$

V: **(wrong)** I do not know.

Solution 1:

Question 58

What is the graphical interpretation of $h(\tau)$ in the convolution integral $y_{\text{forced}}(t) = \int_{-\infty}^{+\infty} h(\tau)u(t-\tau)d\tau$?

Potential answers:

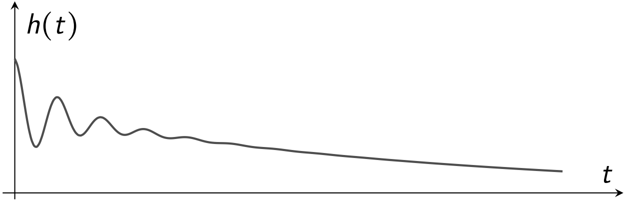
I: **(wrong)** It represents the future inputs of the system.
II: **(correct)** It represents how much past inputs contribute to the current output.
III: **(wrong)** It represents the free evolution of the system.
IV: **(wrong)** It represents the total energy of the system.
V: **(wrong)** I do not know.

Solution 1:

The term $h(\tau)$ in the convolution integral represents how much past inputs $u(t$

Question 59

Which type of LTI system may produce the impulse response $h(t)$ represented in the picture?

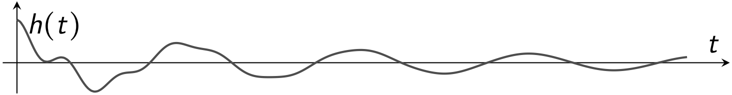


Potential answers:

I: **(wrong)** first order
II: **(wrong)** second order
III: **(correct)** at least third order
IV: **(wrong)** I do not know

Question 60

Which type of LTI system may produce the impulse response $h(t)$ represented in the picture?



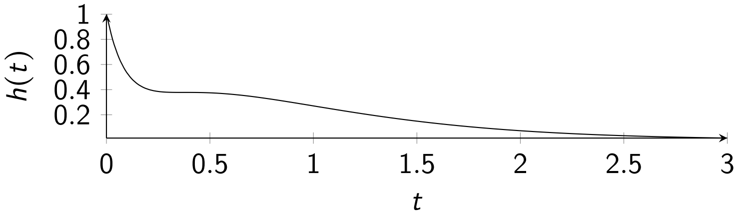
Potential answers:

I: **(wrong)** first order
II: **(wrong)** second order
III: **(wrong)** third order
IV: **(correct)** at least fourth order
V: **(wrong)** I do not know

Solution 1:

Question 61

Which type of LTI system may produce the impulse response $h(t)$ below?



Potential answers:

I:	**(wrong)**	first order
II:	**(wrong)**	second order
III:	**(correct)**	at least third order
IV:	**(wrong)**	I do not know

Question 62

What is the primary purpose of using Laplace transforms in solving LTI systems?

Potential answers:

I: **(wrong)** To convert differential equations into algebraic equations for easier solving.
II: **(correct)** To transform convolution in the time domain into multiplication in the Laplace domain.
III: **(wrong)** To directly compute the eigenvalues of the system matrix.
IV: **(wrong)** To eliminate the need for initial conditions in solving differential equations.
V: **(wrong)** I do not know.

Solution 1:

Question 63

What is the correct form of the inverse Laplace transform of $\dfrac{1}{(s-\lambda)^2}$?

Potential answers:

I:	**(wrong)**	$e^{\lambda t}$
II:	**(wrong)**	$te^{\lambda t}$
III:	**(correct)**	$te^{\lambda t}$
IV:	**(wrong)**	$\frac{1}{2}t^2e^{\lambda t}$
V:	**(wrong)**	I do not know.

Solution 1:

The inverse Laplace transform of $\dfrac{1}{(s-\lambda)^2}$ is $te^{\lambda t}$.

Question 64

What is the inverse Laplace transform of $\frac{s+1}{(s+1)^2+4}$?

Potential answers:

I: **(wrong)** $e^{-t}\sin(2t)$
II: **(correct)** $e^{-t}\cos(2t)$
III: **(wrong)** $e^{-t}\cos(t)$
IV: **(wrong)** $e^{-t}\sin(t)$
V: **(wrong)** I do not know.

Solution 1:

The inverse Laplace transform of $\frac{s+1}{(s+1)^2+4}$ is $e^{-t}\cos(2t)$.

Question 65

In the ARMA model $y^{(n)} = a_{n-1}y^{(n-1)} + \ldots + a_0 y + b_m u^{(m)} + \ldots + b_0 u$, why is the leading coefficient of $y^{(n)}$ typically set to 1?

Potential answers:

I: **(wrong)** To ensure the system is stable.
II: **(wrong)** To simplify the computation of eigenvalues.
III: **(correct)** To reduce the number of parameters and work with monic polynomials.
IV: **(wrong)** To make the system linear time-invariant.
V: **(wrong)** I do not know.

Solution 1:

The leading coefficient of $y^{(n)}$ is typically set to 1 to reduce the number of

Question 66

What determines the coefficients α_1 and α_2 in the free evolution response $y(t) = \alpha_1 e^{-0.3t} + \alpha_2 e^{-1.6t}$?

Potential answers:

I:	**(wrong)**	The eigenvalues of the system matrix.
II:	**(wrong)**	The input signal $u(t)$.
III:	**(correct)**	The initial conditions of the system.
IV:	**(wrong)**	The poles of the transfer function.
V:	**(wrong)**	I do not know.

Solution 1:

The coefficients α_1 and α_2 are determined by the initial conditions of the system.

Question 67

What is the primary purpose of the separation principle in state space representations?

Potential answers:

I: **(wrong)** To ensure that the system has an infinite number of states.
II: **(wrong)** To eliminate the need for inputs in the system model.
III: **(correct)** To ensure that the current state contains all information needed to predict future behavior.
IV: **(wrong)** To simplify the computation of system eigenvalues.
V: **(wrong)** I do not know.

Solution 1:

The separation principle ensures that the current state contains all the information necessary to predict the future evolution of the system, given the future inputs.

Question 68

Which of the following is a valid state variable in a state space representation of a dynamical system?

Potential answers:

I:	**(wrong)**	The external force applied to the system.
II:	**(correct)**	The displacement of a mass in a spring-mass system.
III:	**(wrong)**	The color of the system components.
IV:	**(wrong)**	The temperature of the environment.
V:	**(wrong)**	I do not know.

Solution 1:

The displacement of a mass in a spring-mass system is a valid state variable because it describes the system's configuration and is essential for predicting its

Question 69

What does the state transition map $\boldsymbol{f}$ in a state space representation describe?

Potential answers:

I: **(wrong)** The relationship between inputs and outputs.
II: **(correct)** The evolution of the state variables over time.
III: **(wrong)** The effect of disturbances on the system.
IV: **(wrong)** The stability of the system.
V: **(wrong)** I do not know.

Solution 1:

The state transition map $\boldsymbol{f}$ describes how the state variables evolve over time based on the current state and inputs. It is a key component of state space representations.

Question 70

What is the role of the output map $\boldsymbol{g}$ in a state space representation?

Potential answers:

I: **(wrong)** To define the system's stability.
II: **(wrong)** To describe the evolution of the state variables.
III: **(correct)** To relate the state variables and inputs to the measured outputs.
IV: **(wrong)** To eliminate the need for disturbances in the model.
V: **(wrong)** I do not know.

Solution 1:

The output map $\boldsymbol{g}$ relates the state variables and inputs to the measured outputs. It defines how the system's internal state is reflected in the observable outputs.

Question 71

Which of the following pairs of variables is sufficient to describe the state of a simple pendulum system?

Potential answers:

I:	**(wrong)**	The mass of the pendulum and the length of the string.
II:	**(wrong)**	The external torque and the angular displacement.
III:	**(correct)**	The angular displacement and the angular velocity.
IV:	**(wrong)**	The color of the pendulum and the gravitational constant.
V:	**(wrong)**	I do not know.

Solution 1:

The angular displacement and the angular velocity are sufficient to describe the state of a simple pendulum system because they capture the system's current

Exercise: find which parts of these paragraphs are correct and which ones are wrong

The RCL circuit can be modeled by a second-order linear differential equation where the inductance, resistance, and capacitance determine the system's resonance frequency. Interestingly, in an underdamped RCL circuit, the system will always return to equilibrium without oscillating, which reflects the energy dissipation in the resistor.

Exercise: find which parts of these paragraphs are correct and which ones are wrong

The Lotka-Volterra model is a non-linear system that describes interactions between two species: one as a predator and the other as prey. The model assumes that the growth rate of the prey population is proportional to the current population size, which would mean that the population would grow indefinitely in the absence of predators. Similarly, the predator population is dependent solely on the availability of prey, implying that predators could not survive without prey even if there were other food sources available.

Exercise: find which parts of these paragraphs are correct and which ones are wrong

The Van der Pol oscillator is an example of a non-linear system that exhibits limit cycle behavior. This behavior is critical as it shows how the system can maintain a stable oscillation regardless of initial conditions, which is a feature not present in linear oscillators. It's important to note that the Van der Pol oscillator can only have a single limit cycle, and any perturbations will lead to a quick return to this cycle, indicating that the system is highly stable.

Question 72

What is the role of $(sI - A)^{-1}$ in the derivation of the transfer function from a state-space model?

Potential answers:

I: **(wrong)** It represents the output matrix C.
II: **(correct)** It is used to solve for the state vector $X(s)$ in the Laplace domain.
III: **(wrong)** It defines the input matrix B.
IV: **(wrong)** It is the Laplace transform of the state transition matrix.
V: **(wrong)** I do not know

Solution 1:

$(sI - A)^{-1}$ is used to solve for the state vector $X(s)$ in the Laplace domain. It

Question 73

What is the structure of the A matrix in the control canonical form of a state-space model?

Potential answers:

I: **(correct)** An upper Hessenberg matrix with a lower diagonal of ones and coefficients on the first row from the denominator polynomial.
II: **(wrong)** A diagonal matrix with the eigenvalues of the system.
III: **(wrong)** A lower triangular matrix with zeros on the diagonal.
IV: **(wrong)** A symmetric matrix with off-diagonal elements equal to zero.
V: **(wrong)** I do not know

Solution 1:

The A matrix in control canonical form is an upper Hessenberg matrix with a

Question 74

What is the purpose of the integrator block in the conversion from ARMA to state-space models?

Potential answers:

I:	**(wrong)**	To differentiate the input signal.
II:	**(wrong)**	To invert the Laplace transform of the output.
III:	**(correct)**	To construct the state variables as a chain of scaled integrators.
IV:	**(wrong)**	To compute the determinant of the state matrix.
V:	**(wrong)**	I do not know

Solution 1:

The integrator block is used to construct the state variables as a chain of scaled integrators. This allows us to define the state vector $\mathbf{x}$ and build the state-space

Question 75

What does the transfer function $H(s) = \frac{Y(s)}{U(s)}$ represent in the context of state-space models?

Potential answers:

I: **(wrong)** The state transition matrix.
II: **(wrong)** The input matrix B.
III: **(wrong)** The determinant of the state matrix.
IV: **(correct)** The relationship between the input $U(s)$ and the output $Y(s)$ in the Laplace domain.
V: **(wrong)** I do not know

Solution 1:

$Y(s)$

Question 76

In the context of SISO systems, what are the dimensions of the matrices C and B in a state space representation?

Potential answers:

I:	**(wrong)**	C is a scalar, and B is a vector.
II:	**(correct)**	C is a row vector, and B is a column vector.
III:	**(wrong)**	C is a square matrix, and B is a scalar.
IV:	**(wrong)**	C is a column vector, and B is a row vector.
V:	**(wrong)**	I do not know

Solution 1:

In SISO systems, C is a row vector ($1 \times n$), and B is a column vector ($n \times 1$). This is because C maps the state vector to the output, and B maps the input to the

Question 77

Given the state-space matrices $A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$, $B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$, $C = \begin{bmatrix} 1 & 0 \end{bmatrix}$, and $D = \begin{bmatrix} 0 \end{bmatrix}$, what is the transfer function $H(s)$?

Potential answers:

I: **(<u>correct</u>)** $H(s) = \dfrac{s-4}{s^2-5s-2}$

II: **(<u>wrong</u>)** $H(s) = \dfrac{s-1}{s^2-5s-2}$

III: **(<u>wrong</u>)** $H(s) = \dfrac{s+3}{s^2-5s-2}$

IV: **(<u>wrong</u>)** $H(s) = \dfrac{s-2}{s^2-5s-2}$

V: **(<u>wrong</u>)** I do not know

Solution 1:

Question 78

What does a positive eigenvalue imply about the system's behavior along its corresponding eigenspace?

Potential answers:

I: **(correct)** The state grows exponentially along that eigenspace.
II: **(wrong)** The state decays exponentially along that eigenspace.
III: **(wrong)** The state oscillates along that eigenspace.
IV: **(wrong)** The state remains constant along that eigenspace.
V: **(wrong)** I do not know.

Solution 1:

A positive eigenvalue implies that the state grows exponentially along the corresponding eigenspace. This is derived from the solution $\boldsymbol{x}(t) = e^{\lambda t}\boldsymbol{x}_0$, where $\lambda > 0$

Question 79

In the context of free evolution of a linear time-invariant (LTI) system, what does the equation $\dot{\boldsymbol{x}} = A\boldsymbol{x}$ represent?

Potential answers:

I: **(wrong)** The evolution of the system's output over time.
II: **(correct)** The evolution of the state variables over time, influenced by the system matrix A.
III: **(wrong)** The relationship between input and output signals in the system.
IV: **(wrong)** The response of the system to external inputs.
V: **(wrong)** I do not know

Solution 1:

The equation $\dot{\boldsymbol{x}} = A\boldsymbol{x}$ describes the free evolution of the system's state variables

Question 80

Why is it useful to consider the eigendecomposition of the system matrix A in analyzing the free evolution of state variables?

Potential answers:

I: **(wrong)** It simplifies calculating the system's forced response.

II: **(wrong)** It directly determines the output y of the system.

III: **(correct)** It helps identify invariant directions (eigenvectors) and growth/decay rates (eigenvalues) that govern the system's behavior over time.

IV: **(wrong)** It only affects the graphical representation, not the actual system behavior.

V: **(wrong)** I do not know

Solution 1:

Question 81

In a graphical representation, what does the matrix-vector product $A\boldsymbol{x}$ illustrate in the context of system dynamics?

Potential answers:

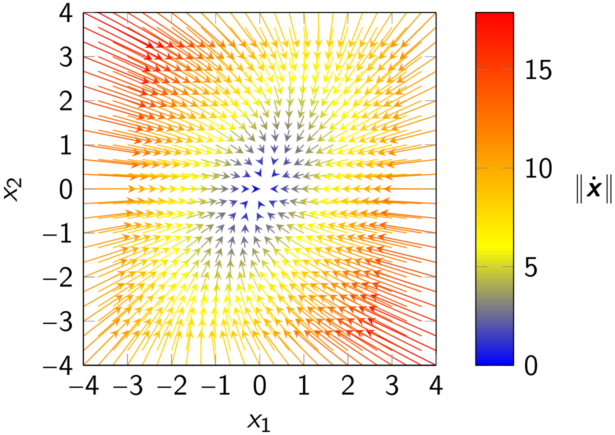
I:	**(wrong)**	The projection of the state vector onto the output space.
II:	**(wrong)**	The response of the system to a unit impulse.
III:	**(correct)**	Where the trajectory of the system is going, starting from $\boldsymbol{x}$.
IV:	**(wrong)**	The change in the input signal over time.
V:	**(wrong)**	I do not know

Solution 1:

The product $A\boldsymbol{x}$ represents $\dot{\boldsymbol{x}}$, that indicates the system's dynamics on the state evolution.

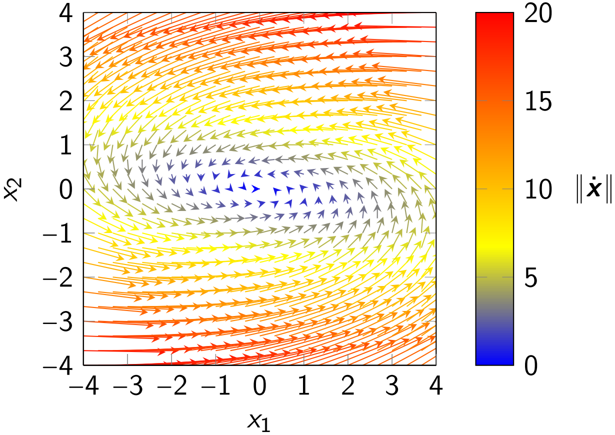
Question 82

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



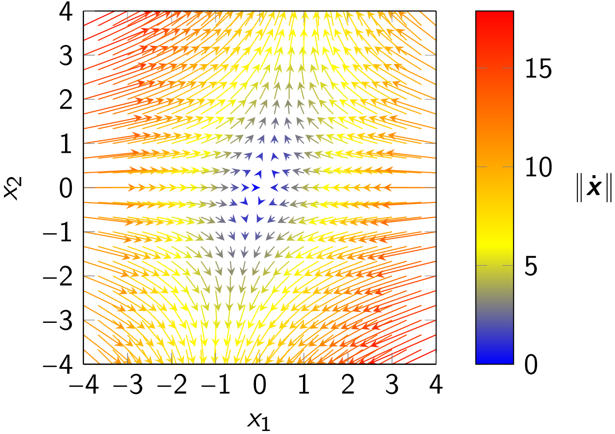
Question 83

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



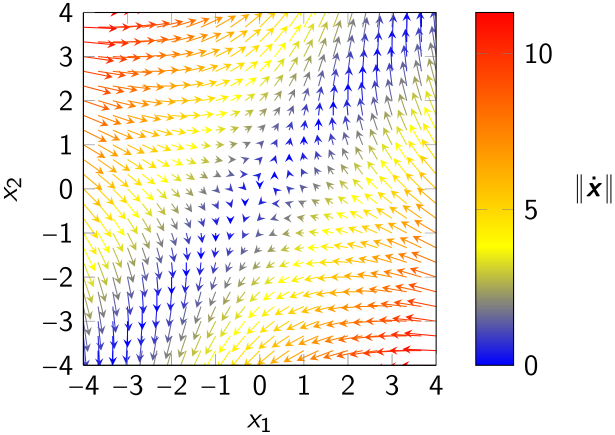
Question 84

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



Question 85

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



Question 86

Does the concept of marginal stability of an equilibrium apply only to LTI systems?

Potential answers:

I: **(wrong)** Yes, marginal stability is defined only for LTI systems.
II: **(correct)** No, marginal stability can be defined for nonlinear systems as well.
III: **(wrong)** Marginal stability is irrelevant for LTI systems.
IV: **(wrong)** It only applies to mechanical systems.
V: **(wrong)** I do not know

Solution 1:

Marginal stability is a property that can be analyzed for both LTI and nonlinear systems. While it is often introduced in the context of LTI systems, the concept

Question 87

Does the concept of marginal stability of an equilibrium apply only to continuous-time systems?

Potential answers:

I: **(wrong)** Yes, marginal stability is only defined for continuous-time systems.

II: **(wrong)** No, but it is more relevant in continuous-time systems.

III: **(wrong)** No, discrete-time systems do not have equilibria.

IV: **(correct)** No, marginal stability can be defined for both continuous and discrete-time systems.

V: **(wrong)** I do not know

Solution 1:

Question 88

In the game of marginal stability, who starts? The boss or the apprentice?

Potential answers:

I: **(wrong)** The apprentice, since they test small perturbations.
II: **(correct)** The boss, since the system dynamics dictate the response.
III: **(wrong)** They both start at the same time.
IV: **(wrong)** There is no turn-based order in stability analysis.
V: **(wrong)** I do not know

Solution 1:

The system dynamics, dictated by the governing equations ("the boss"), determine how the state evolves. The "apprentice" (perturbations) follows.

Question 89

If a system has a marginally stable equilibrium, then all its equilibria must be marginally stable. Is this statement correct?

Potential answers:

I: **(correct)** No, stability properties are equilibrium-dependent.
II: **(wrong)** Yes, if one equilibrium is marginally stable, all others must be as well.
III: **(wrong)** The question is meaningless because marginal stability does not exist.
IV: **(wrong)** Only if the system is conservative.
V: **(wrong)** I do not know

Solution 1:

Question 90

Is the origin for the Lotka-Volterra model simply stable?

Potential answers:

I: **(correct)** No, it is a saddle point and therefore unstable.
II: **(wrong)** Yes, because populations always return to equilibrium.
III: **(wrong)** Yes, because it has only non-positive eigenvalues.
IV: **(wrong)** It depends on the initial conditions.
V: **(wrong)** I do not know

Solution 1:

The origin in the Lotka-Volterra model is typically a saddle point, meaning small perturbations in certain directions grow, making it unstable.

Question 91

Which of the following statements is true regarding the BIBO stability of an LTI system?

Potential answers:

I: **(wrong)** A system is BIBO stable if its impulse response is periodic.
II: **(correct)** A system is BIBO stable if and only if its impulse response is absolutely integrable.
III: **(wrong)** A system is BIBO stable if and only if all its eigenvalues have negative real parts.
IV: **(wrong)** A system is BIBO stable if its impulse response is non-negative.
V: **(wrong)** I do not know.

Solution 1:

Question 92

Which of the following impulse responses corresponds to a BIBO stable system?

Potential answers:

I: **(wrong)** $h(t) = e^t$ for $t < 0$, $h(t) = 0$ for $t \geq 0$.
II: **(wrong)** $h(t) = \sin(t)$.
III: **(correct)** $h(t) = e^{-t}\mathrm{step}(t)$, where $\mathrm{step}(t)$ is the unit step function.
IV: **(correct)** $h(t) = \frac{1}{1+t^2}$ for all t.
V: **(wrong)** I do not know.

Solution 1:

The impulse response $h(t) = e^{-t}\mathrm{step}(t)$ is absolutely integrable because $\int_0^\infty e^{-t}dt = 1$, which is finite, ensuring BIBO stability. $h(t) = \frac{1}{1+t^2}$ for all

Question 93

A system has an impulse response $h(t)$ such that $\int_{-\infty}^{+\infty} |h(t)| dt$ diverges. What does this imply?

Potential answers:

I:	**(wrong)**	The system is asymptotically stable.
II:	**(correct)**	The system is not BIBO stable.
III:	**(wrong)**	The system has a finite impulse response (FIR).
IV:	**(wrong)**	The system must have at least one pole in the right-half plane.
V:	**(wrong)**	I do not know.

Solution 1:

If the impulse response is not absolutely integrable, then the system is not BIBO stable. This means there exist bounded inputs that produce unbounded outputs.

Question 94

Consider an LTI system with impulse response $h(t) = \dfrac{1}{1+t^2}$. What can be said about its BIBO stability?

Potential answers:

I: **(correct)** The system is BIBO stable because its impulse response is absolutely integrable.

II: **(wrong)** The system is not BIBO stable because its impulse response is not causal.

III: **(wrong)** The system is not BIBO stable because its impulse response is not exponentially decaying.

IV: **(wrong)** The system is marginally stable.

V: **(wrong)** I do not know.

Solution 1:

Question 95

Which of the following statements correctly describes a BIBO unstable system?

Potential answers:

I: **(<u>wrong</u>)** A BIBO unstable system has a stable impulse response.
II: **(<u>wrong</u>)** A BIBO unstable system has a bounded output for every bounded input.
III: **(<u>wrong</u>)** A BIBO unstable system has a finite impulse response.
IV: **(<u>correct</u>)** A BIBO unstable system has at least one bounded input that produces an unbounded output.
V: **(<u>wrong</u>)** I do not know.

Solution 1:

A BIBO unstable system has at least one bounded input that produces an un-

Question 96

Which of the following best describes what it means for a function $y[k]$ to be a solution of a RR?

Potential answers:

I:	**(wrong)**	It satisfies the RR for at least one value of k.
II:	**(correct)**	It satisfies the RR for all values of k in its domain.
III:	**(wrong)**	It approximately satisfies the RR within a certain error margin.
IV:	**(wrong)**	It satisfies the RR only at integer values of k.
V:	**(wrong)**	I do not know

Solution 1:

A function is a solution of a RR if it satisfies the equation for all values of k within its domain. A solution must be valid throughout the considered interval.

Question 97

What additional information is needed to uniquely determine a solution of a RR?

Potential answers:

I:	**(wrong)**	The function $y[k]$ itself.
II:	**(correct)**	An initial condition specifying the value of y at a given time.
III:	**(wrong)**	A boundary condition at two different points.
IV:	**(wrong)**	The highest-order difference of y.
V:	**(wrong)**	I do not know

Solution 1:

An initial condition provides the necessary information to select a unique solution from the family of possible solutions to a differential equation. Without it, multiple solutions may exist.

Question 98

Given the RR $y^+ = y$, which of the following functions is a solution?

Potential answers:

I: **(wrong)** $y[k] = 0$

II: **(correct)** $y[k] = C$, where C is a constant.

III: **(wrong)** $y[k] = \sin k$

IV: **(wrong)** $y[k] = \frac{1}{k+1}$

V: **(wrong)** I do not know

Solution 1:

The function $y[k] = C$ satisfies the equation since it matches the right-hand side of the RR.

Question 99

What is the correct process to verify if a given time series $y[k]$ is a solution to a specified recurrence relation?

Potential answers:

I: **(wrong)** Check if $y[k]$ has the same general form as other solutions to the recurrence relation

II: **(wrong)** Analyze the stability properties of $y[k]$ to see if they match the recurrence relation

III: **(correct)** Compute $y[k+1]$ from the time series and check if $f(y[k]) = y[k+1]$

IV: **(wrong)** Find the transfer function of the recurrence relation and apply it to $y[k]$

V: **(wrong)** I do not know

Question 100

In the notation for discrete-time signals presented in the slides, what does the expression yq^{-2} represent?

Potential answers:

I:	**(wrong)**	The second derivative of $y[k]$
II:	**(correct)**	The value of y at time $k-2$, i.e., $y[k-2]$
III:	**(wrong)**	The value of y at time $k+2$, i.e., $y[k+2]$
IV:	**(wrong)**	The result of dividing $y[k]$ by q^2
V:	**(wrong)**	I do not know

Solution 1:

According to the notation presented in the slides, yq^{-2} represents the value of y at time $k-2$, which is written as $y[k-2]$ in standard notation. This is equivalent

Question 101

What is the discrete-time equivalent of a derivative for a time series $y[k]$ as presented in the slides?

Potential answers:

I: **(wrong)** $y[k+1] - y[k]$

II: **(wrong)** $(y[k+1] + y[k])/T$

III: **(correct)** $\dfrac{y[k] - y[k-1]}{T} = y[k]\left(\dfrac{1-q^{-1}}{T}\right)$

IV: **(wrong)** $\dfrac{y[k+1] - y[k-1]}{2T}$

V: **(wrong)** I do not know

Solution 1:

The discrete-time equivalent of a derivative for a time series is given by

Question 102

Is a recurrence relation alone sufficient to generate a unique trajectory of a dynamical system?

Potential answers:

I: **(correct)** No, initial conditions are also required to generate a unique trajectory

II: **(wrong)** Yes, the recurrence relation completely defines the trajectory regardless of starting point

III: **(wrong)** Yes, but only if the recurrence relation is linear

IV: **(wrong)** No, we also need the final conditions to uniquely determine the trajectory

V: **(wrong)** I do not know

Solution 1:

Question 103

In the general form of modeling a dynamical system $\boldsymbol{y}^{+} = \boldsymbol{f}(\boldsymbol{y}, \boldsymbol{u}, \boldsymbol{d}, \boldsymbol{\theta})$, which of the following statements about $\boldsymbol{u}$ is correct?

Potential answers:

- I: **(wrong)** $\boldsymbol{u}$ represents the outputs that we are interested in studying
- II: **(wrong)** $\boldsymbol{u}$ represents the disturbances that influence the system but cannot be controlled
- III: **(correct)** $\boldsymbol{u}$ represents the inputs that we can steer or control
- IV: **(wrong)** $\boldsymbol{u}$ represents the parameters that define the shape of function $\boldsymbol{f}$
- V: **(wrong)** I do not know

Solution 1:

In the general form of modeling a dynamical system $\boldsymbol{y}^{+} = \boldsymbol{f}(\boldsymbol{y}, \boldsymbol{u}, \boldsymbol{d}, \boldsymbol{\theta})$, $\boldsymbol{u}$ rep-

Question 104

Which of the following is the most important general key factor affecting the accuracy of Euler's forward method when discretizing ODEs?

Potential answers:

- I: **(correct)** The step size T
- II: **(wrong)** The initial condition $y(0)$
- III: **(wrong)** The type of input signal $u(t)$
- IV: **(wrong)** The order of the ODE
- V: **(wrong)** I do not know

Solution 1:

The step size T is in general the most important key factor affecting the accuracy of Euler's forward method. A smaller T generally leads to a more accurate

Question 105

What is a common issue when using Euler's forward method to solve stiff ODEs?

Potential answers:

I:	**(correct)**	Numerical instability
II:	**(wrong)**	Increased computational efficiency
III:	**(wrong)**	Exact solution with no error
IV:	**(wrong)**	Reduced sensitivity to initial conditions
V:	**(wrong)**	I do not know

Solution 1:

Stiff ODEs often lead to numerical instability when using Euler's forward method due to the high sensitivity of the solution to small changes in the state.

Question 106

Which of the following is a tradeoff when using Euler's forward method for ODE discretization?

Potential answers:

I: **(wrong)** Smaller step size T reduces accuracy and increases CPU time
II: **(wrong)** Larger step size T reduces accuracy and increases CPU time
III: **(correct)** Smaller step size T increases accuracy but also increases CPU time
IV: **(wrong)** Larger step size T increases accuracy and reduces CPU time
V: **(wrong)** I do not know

Solution 1:

A smaller step size T improves the accuracy of the Euler forward method but

Question 107

What is the main difference between Euler's forward and backward methods?

Potential answers:

I: **(wrong)** Euler's backward method is always more accurate than Euler's forward method
II: **(wrong)** Euler's backward method does not require an initial condition
III: **(correct)** Euler's backward method uses the derivative at the next time step
IV: **(wrong)** Euler's backward method cannot be used for stiff ODEs
V: **(wrong)** I do not know

Solution 1:

Euler's backward method uses the derivative at the next time step, making it an

Question 108

When discretizing a continuous-time ARMA model using Euler's backward method, what substitution is made for the first derivative $\frac{dy(t)}{dt}$?

Potential answers:

I: (**correct**) $\frac{1-q^{-1}}{T}$
II: (**wrong**) $\frac{q-1}{T}$
III: (**wrong**) $\frac{q+1}{T}$
IV: (**wrong**) $\frac{1+q^{-1}}{T}$
V: (**wrong**) I do not know

Solution 1:

Question 109

Which of the following autonomous systems is nonlinear?

Potential answers:

I: **(correct)** $y^+ = 3y + 5$
II: **(correct)** $y^+ = y^2 + 3y$
III: **(correct)** $y^+ = 2y - 4$
IV: **(wrong)** $y^+ = -0.5y$
V: **(wrong)** I do not know

Solution 1:

A differential equation is nonlinear if it includes terms such as y^2, $\sin(y)$, or e^y. The equation $y^+ = y^2 + 3y$ contains a quadratic term, making it nonlinear. The solutions $3y + 5$ and $2y - 4$ are affine, and thus nonlinear.

Question 110

Which of the following differential equations is autonomous?

Potential answers:

I: **(correct)** $y^+ = -2y + 5$
II: **(wrong)** $y^+ = 3y + \sin(t)$
III: **(wrong)** $y^+ = ty - 4$
IV: **(wrong)** $y^+ = e^t - y$
V: **(wrong)** I do not know

Solution 1:

A system is autonomous if its dynamics do not explicitly depend on time t. The equation $y^+ = -2y + 5$ only depends on y and is therefore autonomous. The other options include explicit dependence on t.

Question 111

Which of the following equations represents a time-invariant system?

Potential answers:

I: **(correct)** $y^+ = 4y + u$
II: **(wrong)** $y^+ = 2ty$
III: **(wrong)** $y^+ = \sin(t)y$
IV: **(wrong)** $y^+ = y + 3t$
V: **(wrong)** I do not know

Solution 1:

A system is time-invariant if its coefficients do not explicitly depend on time. The equation $y^+ = 4y + u$ meets this criterion, whereas the other options contain explicit time dependencies.

Question 112

Consider the equation $y^+ = -0.3y + (2t)u$. How should this system be classified?

Potential answers:

I:	**(wrong)**	Linear, autonomous, time-invariant
II:	**(wrong)**	Linear, autonomous, time-varying
III:	**(correct)**	Linear, non-autonomous, time-varying
IV:	**(wrong)**	Nonlinear, non-autonomous, time-varying
V:	**(wrong)**	I do not know

Solution 1:

The system is linear because it contains no nonlinear terms in y or in u. It is non-autonomous due to the explicit dependence on u, and it is time-varying since the coefficient of u depends on t.

Question 113

Which function represents a linear system?

Potential answers:

I:	**(wrong)**	$y^+ = y^3 + 2y$
II:	**(correct)**	$y^+ = 5y + 3u$
III:	**(wrong)**	$y^+ = \sin(y) + u$
IV:	**(wrong)**	$y^+ = e^y - u$
V:	**(wrong)**	I do not know

Solution 1:

A system is linear if it satisfies the superposition principle. The equation $y^+ = 5y + 3u$ is linear because it only includes first-degree terms in y and u. The other options contain nonlinear terms such as y^3, $\sin(y)$, or e^y.

Question 114

Which of the following best defines an equilibrium point in a dynamical system?

Potential answers:

I: **(wrong)** A point where the system's state constantly increases.
II: **(correct)** A point where the system's state remains unchanged over time.
III: **(wrong)** A point where the system's state oscillates periodically.
IV: **(wrong)** A point where the system's state diverges exponentially.
V: **(wrong)** I do not know

Solution 1:

An equilibrium point is defined as a state where the system remains unchanged over time, meaning $y^+ = y$.

Question 115

How can equilibrium points be identified in a graphical representation of $y^+ = f(y)$?

Potential answers:

I: **(wrong)** At points where $f(y)$ reaches its maximum value.
II: **(wrong)** At points where $f(y)$ crosses the y-axis.
III: **(wrong)** At points where $f(y)$ is strictly increasing.
IV: **(correct)** At points where $f(y) = y$, indicating that the system remains unchanged.
V: **(wrong)** I do not know

Solution 1:

Equilibrium points are found where $y^+ = f(y)$ intersects the identity line $y^+ = y$, ensuring that the state remains constant.

Question 116

Which of the following systems is most likely to be in equilibrium?

Potential answers:

I:	**(wrong)**	A ball rolling down a hill.
II:	**(correct)**	A balancing robot standing perfectly upright and not moving.
III:	**(wrong)**	A pendulum swinging back and forth.
IV:	**(wrong)**	A falling hailstone.
V:	**(wrong)**	I do not know

Solution 1:

An equilibrium state occurs when there is no change in the systems state over time, such as when a balancing robot remains perfectly upright without movement.

Question 117

For the discrete-time system $y^+ = 0.5y + 10$, what is the equilibrium value of y?

Potential answers:

I: **(wrong)** 0
II: **(wrong)** 10
III: **(correct)** 20
IV: **(wrong)** 40
V: **(wrong)** I do not know

Solution 1:

To find equilibrium, solve $y^+ = y$:

$y = 0.5y + 10$

$y - 0.5y = 10$

Question 118

In a linear time-invariant system, an equilibrium point can be computed by:

Potential answers:

I: (**correct**) Setting the system dynamics to zero and solving for state and input values.
II: (**wrong**) Taking the time derivative of the system matrix.
III: (**wrong**) Finding the eigenvalues of the system matrix.
IV: (**wrong**) Taking the integral of the system dynamics.
V: (**wrong**) I do not know

Solution 1:

Equilibrium is found by setting $y^+ = y$ in the system equation and solving for the corresponding state and input values.

Question 119

What is the primary purpose of a phase portrait for a discrete-time system?

Potential answers:

I: **(wrong)** To compute the exact solution of the system
II: **(correct)** To visualize the qualitative behavior of the system's trajectories in state space
III: **(wrong)** To determine the numerical stability of the system
IV: **(wrong)** To solve the system's differential equations analytically
V: **(wrong)** I do not know

Solution 1:

The primary purpose of a phase portrait is to visualize the qualitative behavior of the system's trajectories in state space, including equilibria, stability, and general

Question 120

What happens to the accuracy of a discrete-time system's phase portrait as the discretization time T decreases?

Potential answers:

I: **(wrong)** The phase portrait becomes less accurate

II: **(correct)** The phase portrait becomes more accurate, converging to the continuous-time solution

III: **(wrong)** The phase portrait remains unchanged

IV: **(wrong)** The phase portrait becomes unstable

V: **(wrong)** I do not know

Solution 1:

As T decreases, the discrete-time system's phase portrait becomes more accurate,

Question 121

When discretizing the Lotka-Volterra model, what is the effect of changing the discretization time T?

Potential answers:

I: **(wrong)** The system's equilibria change
II: **(correct)** The parameters of the discretized system change, leading to different approximations
III: **(wrong)** The system becomes unstable
IV: **(wrong)** The system's trajectories become chaotic
V: **(wrong)** I do not know

Solution 1:

Changing the discretization time T alters the parameters of the discretized sys-

Question 122

What does a stable equilibrium point in a discrete-time phase portrait indicate?

Potential answers:

I: **(wrong)** Trajectories diverge away from the equilibrium point
II: **(correct)** Trajectories converge to the equilibrium point over time
III: **(wrong)** The system exhibits periodic behavior
IV: **(wrong)** The system becomes chaotic
V: **(wrong)** I do not know

Solution 1:

A stable equilibrium point in a discrete-time phase portrait indicates that trajectories converge to the equilibrium point over time.

Question 123

What does a closed loop in a discrete-time phase portrait typically represent?

Potential answers:

I: **(wrong)** A stable equilibrium point
II: **(wrong)** An unstable equilibrium point
III: **(correct)** Periodic or quasi-periodic behavior
IV: **(wrong)** Chaotic behavior
V: **(wrong)** I do not know

Solution 1:

A closed loop in a discrete-time phase portrait typically represents periodic or quasi-periodic behavior, where the system's state repeats over time.

Question 124

Which of the following is a key disadvantage of open-loop control compared to closed-loop control?

Potential answers:

I:	**(wrong)**	It requires more computational resources.
II:	**(correct)**	It cannot correct for disturbances or system variations.
III:	**(wrong)**	It is slower to respond to changes.
IV:	**(wrong)**	It is more expensive to implement.
V:	**(wrong)**	I do not know.

Solution 1:

The key disadvantage of open-loop control is that it cannot correct for disturbances or system variations. Unlike closed-loop control, which uses feedback to

Question 125

What is the primary purpose of the integral term (K_i) in a PID controller?

Potential answers:

I: **(wrong)** To amplify the current error.
II: **(correct)** To eliminate steady-state error by summing past errors.
III: **(wrong)** To predict future errors based on the current trend.
IV: **(wrong)** To reduce the sensitivity to noise.
V: **(wrong)** I do not know.

Solution 1:

The primary purpose of the integral term (K_i) in a PID controller is to eliminate steady-state error by summing past errors over time. This ensures that the system reaches the desired setpoint without any residual error.

Question 126

What is a key advantage of Model Predictive Control (MPC) over PID control?

Potential answers:

I:	**(wrong)**	It requires less computational power.
II:	**(wrong)**	It is easier to tune.
III:	**(correct)**	It can handle constraints and optimize future behavior.
IV:	**(wrong)**	It is always more stable.
V:	**(wrong)**	I do not know.

Solution 1:

A key advantage of Model Predictive Control (MPC) over PID control is its ability to handle constraints and optimize future behavior. MPC uses a model of the system to predict future states and optimize control actions over a finite horizon

Question 127

In a combined feedforward and feedback control system, what is the role of the feedforward component?

Potential answers:

I: **(wrong)** To correct for errors after they occur.
II: **(correct)** To compensate for known disturbances before they affect the system.
III: **(wrong)** To measure the system output and adjust the control action.
IV: **(wrong)** To reduce the computational load of the feedback controller.
V: **(wrong)** I do not know.

Solution 1:

In a combined feedforward and feedback control system, the role of the feedfor-

Question 128

What is the main goal of automatic control in the context of system dynamics?

Potential answers:

I: **(wrong)** To increase the complexity of the system.
II: **(correct)** To manipulate the system's dynamics to achieve a desired behavior.
III: **(wrong)** To eliminate all disturbances from the system.
IV: **(wrong)** To reduce the need for sensors and actuators.
V: **(wrong)** I do not know.

Solution 1:

The main goal of automatic control in the context of system dynamics is to manipulate the system's dynamics to achieve a desired behavior. This involves de-

Question 129

What is the primary purpose of linearizing a nonlinear system around an equilibrium point?

Potential answers:

I: **(correct)** To approximate the system's behavior in a small neighborhood of the equilibrium.
II: **(wrong)** To completely replace the nonlinear system with a linear one globally.
III: **(wrong)** To eliminate all nonlinearities in the system.
IV: **(wrong)** To make the system unstable for control purposes.
V: **(wrong)** I do not know

Solution 1:

Question 130

Which of the following is a necessary condition for linearizing a function $f(y)$ around a point $\overline{y}$?

Potential answers:

I: **(<u>correct</u>)** The function $f(y)$ must be differentiable at $\overline{y}$.
II: **(<u>wrong</u>)** The function $f(y)$ must be discontinuous at $\overline{y}$.
III: **(<u>wrong</u>)** The function $f(y)$ must be constant in a neighborhood of $\overline{y}$.
IV: **(<u>wrong</u>)** The function $f(y)$ must be linear globally.
V: **(<u>wrong</u>)** I do not know

Solution 1:

A necessary condition for linearizing a function $f(y)$ around a point $\overline{y}$ is that the function must be differentiable at $\overline{y}$. This ensures that the Taylor series expansion

Question 131

What is the dimension of the Jacobian matrix $\nabla_{\boldsymbol{y}} \boldsymbol{f}$ for a vectorial function $\boldsymbol{f} : \mathbb{R}^n \mapsto \mathbb{R}^m$?

Potential answers:

I: **(correct)** $m \times n$
II: **(wrong)** $n \times m$
III: **(wrong)** $n \times n$
IV: **(wrong)** $m \times m$
V: **(wrong)** I do not know

Solution 1:

The Jacobian matrix $\nabla_{\boldsymbol{y}} \boldsymbol{f}$ for a vectorial function $\boldsymbol{f} : \mathbb{R}^n \mapsto \mathbb{R}^m$ has dimensions $m \times n$. This is because it consists of the partial derivatives of each of the m

Question 132

In the context of discrete-time systems, where are the equilibria located?

Potential answers:

I: **(correct)** On the bisector where $y = f(y)$.
II: **(wrong)** On the bisector where $y = u$.
III: **(wrong)** On the bisector where $f(y) = u$.
IV: **(wrong)** On the bisector where $y = 0$.
V: **(wrong)** I do not know

Solution 1:

In discrete-time systems, the equilibria are located on the bisector where $y = f(y)$. This is because, by definition, an equilibrium point satisfies $\boldsymbol{y}_{\text{eq}} = \boldsymbol{f}(\boldsymbol{y}_{\text{eq}}, \boldsymbol{u}_{\text{eq}})$.

Question 133

What is the main limitation of linearizing a nonlinear system around an equilibrium point?

Potential answers:

I: **(correct)** The approximation is only valid in a small neighborhood of the equilibrium.
II: **(wrong)** The linearized system is always unstable.
III: **(wrong)** The linearized system cannot be used for control purposes.
IV: **(wrong)** The linearized system is always globally accurate.
V: **(wrong)** I do not know

Solution 1:

The main limitation of linearizing a nonlinear system around an equilibrium point

Question 134

Which of the following statements about linearization around an equilibrium point is correct?

Potential answers:

I: **(wrong)** Linearization provides a good approximation for any nonlinear system at any point.

II: **(wrong)** Linearization is only useful for stable equilibria and does not work for unstable ones.

III: **(correct)** Linearization can be a good approximation near both stable and unstable equilibria, depending on the time horizon and initial conditions.

IV: **(wrong)** Linearization is only valid if the system has no nonlinear terms.

V: **(wrong)** I do not know

Solution 1:

Question 135

Under which condition is linearization not possible?

Potential answers:

I: **(<u>wrong</u>)** If the equilibrium is unstable.
II: **(<u>wrong</u>)** If the equilibrium is stable but far from the origin.
III: **(<u>correct</u>)** If the system's function is not differentiable at the equilibrium point.
IV: **(<u>wrong</u>)** If the system is highly nonlinear.
V: **(<u>wrong</u>)** I do not know

Solution 1:

Linearization relies on computing the first-order Taylor series expansion, which requires differentiability at the equilibrium point. If the function is not differen-

Question 136

How does the curvature of the nonlinear system affect the validity of linearization?

Potential answers:

I: **(wrong)** Curvature does not affect the validity of linearization.
II: **(wrong)** The larger the curvature, the more accurate the linearized model.
III: **(correct)** The larger the curvature, the more local the validity of the linearized model.
IV: **(wrong)** Linearization is only valid when curvature is zero.
V: **(wrong)** I do not know

Solution 1:

Higher curvature means that the nonlinear system deviates more quickly from its linear approximation, making the linearized model valid only in a smaller neigh-

Question 137

What does the size of the basin of attraction tell us about the linearized model?

Potential answers:

I: **(correct)** A small basin of attraction means the linearized model is only valid in a very restricted region.
II: **(wrong)** A small basin of attraction means the system is globally stable.
III: **(wrong)** A large basin of attraction makes linearization unnecessary.
IV: **(wrong)** The basin of attraction does not affect the validity of the linearization.
V: **(wrong)** I do not know

Solution 1:

If the basin of attraction is small, then trajectories quickly leave the region where

Question 138

In which of the following cases is linearization not meaningful?

Potential answers:

I: **(correct)** When the system has no equilibrium points.
II: **(wrong)** When the equilibrium point is unstable.
III: **(wrong)** When the system is nonlinear.
IV: **(wrong)** When the system has high curvature.
V: **(wrong)** I do not know

Solution 1:

Linearization is performed around an equilibrium point, where the first derivative is evaluated. If no equilibrium exists, linearization is not meaningful.

Question 139

What is the primary implication of the superposition principle in LTI systems?

Potential answers:

I: **(correct)** The total response is the sum of the free evolution and the forced response.
II: **(wrong)** The system response is always exponential.
III: **(wrong)** The system response is independent of the initial conditions.
IV: **(wrong)** The system response is nonlinear.
V: **(wrong)** I do not know

Solution 1:

The superposition principle in LTI systems allows us to decompose the total response into two components: the free evolution (response due to initial con-

Question 140

Which of the following properties is essential for a system to be considered linear?

Potential answers:

I: **(wrong)** The system response is always sinusoidal.
II: **(correct)** The system satisfies the properties $f(x+y) = f(x) + f(y)$ and $f(\alpha y) = \alpha f(y)$.
III: **(wrong)** The system response is independent of the input.
IV: **(wrong)** The system response is always zero for zero input.
V: **(wrong)** I do not know

Solution 1:

For a system to be linear, it must satisfy the properties of additivity ($f(x+y) = f(x) + f(y)$) and homogeneity ($f(\alpha y) = \alpha f(y)$). These properties are

Question 141

What happens to the response of an LTI system if the input is scaled by a factor α?

Potential answers:

I: **(wrong)** The response becomes nonlinear.
II: **(wrong)** The response remains unchanged.
III: **(correct)** The response is scaled by the same factor α.
IV: **(wrong)** The response becomes zero.
V: **(wrong)** I do not know

Solution 1:

In an LTI system, scaling the input by a factor α results in the response being scaled by the same factor α. This is a direct consequence of the homogeneity property of linear systems.

Question 142

What is the significance of the superposition principle in analyzing LTI systems?

Potential answers:

I: **(wrong)** It allows us to ignore the initial conditions.

II: **(correct)** It allows us to decompose the system response into free evolution and forced response.

III: **(wrong)** It makes the system response independent of the input.

IV: **(wrong)** It ensures the system response is always exponential.

V: **(wrong)** I do not know

Solution 1:

The superposition principle is crucial in LTI systems because it allows us to break down the total response into two parts: the free evolution (due to initial con-

Question 143

Which of the following statements is true about the superposition principle in LTI systems?

Potential answers:

I: **(wrong)** It only applies to nonlinear systems.
II: **(wrong)** It is only valid for zero initial conditions.
III: **(correct)** It states that the response to a sum of inputs is the sum of the responses to each input individually.
IV: **(wrong)** It implies that the system response is always sinusoidal.
V: **(wrong)** I do not know

Solution 1:

The superposition principle in LTI systems states that the response to a sum of

Question 144

What is the impulse response of an LTI system?

Potential answers:

I: **(correct)** The output of the system when the input is a discrete Dirac's delta.

II: **(wrong)** The output of the system when the input is a step function.

III: **(wrong)** The output of the system when the input is a sinusoidal signal.

IV: **(wrong)** The output of the system when the input is a random signal.

V: **(wrong)** I do not know

Solution 1:

The impulse response of an LTI system is defined as the output of the system when the input is a discrete Dirac's delta ($\delta[k]$). This response characterizes the

Question 145

Why is the impulse response meaningful only for LTI systems?

Potential answers:

I: **(wrong)** Because nonlinear systems do not have outputs.
II: **(correct)** Because the impulse response relies on the superposition principle, which is valid only for LTI systems.
III: **(wrong)** Because the impulse response is only defined for continuous-time systems.
IV: **(wrong)** Because the impulse response is too complex for nonlinear systems.
V: **(wrong)** I do not know

Solution 1:

Question 146

What happens to the impulse response of a discrete-time LTI system if the input is $\delta[k-4]$?

Potential answers:

I:	**(wrong)**	The impulse response becomes zero.
II:	**(correct)**	The impulse response is shifted by 4 time units.
III:	**(wrong)**	The impulse response is scaled by a factor of 4.
IV:	**(wrong)**	The impulse response becomes nonlinear.
V:	**(wrong)**	I do not know

Solution 1:

For a discrete-time LTI system, if the input is $\delta[k-4]$, the impulse response is shifted by 4 time units. This is a consequence of the time-invariance property of

Question 147

What is the practical significance of the impulse response in analyzing LTI systems?

Potential answers:

I: **(wrong)** It allows us to ignore the system's initial conditions.
II: **(correct)** It characterizes the system's behavior and can be used to determine the output for any input.
III: **(wrong)** It ensures the system response is always sinusoidal.
IV: **(wrong)** It makes the system response independent of the input.
V: **(wrong)** I do not know

Solution 1:

The impulse response is significant because it characterizes the behavior of an LTI system. Once the impulse response is known, the output of the system for

Question 148

In the context of a spring-mass-damper system, what does the impulse response represent?

Potential answers:

I: **(wrong)** The steady-state position of the mass.
II: **(correct)** The displacement of the mass over time after an instantaneous force is applied.
III: **(wrong)** The force required to keep the mass at rest.
IV: **(wrong)** The frequency of oscillation of the mass.
V: **(wrong)** I do not know

Solution 1:

In a spring-mass-damper system, the impulse response represents the displace-

Question 149

What does the convolution integral $y_{\text{forced}}[k] = \sum_{-\infty}^{+\infty} h[\kappa]u[k-\kappa]$ represent in the context of LTI systems?

Potential answers:

I: **(wrong)** The free evolution of the system output.
II: **(correct)** The forced response of the system output due to the input $u[k]$.
III: **(wrong)** The total response of the system, including initial conditions.
IV: **(wrong)** The impulse response of the system.
V: **(wrong)** I do not know.

Solution 1:

$+\infty$

Question 150

Which of the following is true about the convolution operation $h * u[k]$?

Potential answers:

I:	**(<u>wrong</u>)**	It is only defined for periodic signals.
II:	**(<u>wrong</u>)**	It is only applicable to discrete-time systems.
III:	**(<u>correct</u>)**	It is commutative, i.e., $h * u[k] = u * h[k]$.
IV:	**(<u>wrong</u>)**	It requires both signals to be symmetric.
V:	**(<u>wrong</u>)**	I do not know.

Solution 1:

The convolution operation is commutative, meaning $h * u[k] = u * h[k]$. This property holds for continuous-time signals in LTI systems.

Question 151

What does the impulse response $h[k]$ of an LTI system represent?

Potential answers:

I: **(wrong)** The input signal $u[k]$ applied to the system.
II: **(wrong)** The free evolution of the system output.
III: **(wrong)** The total response of the system, including initial conditions.
IV: **(correct)** The output of the system when the input is a Dirac delta function $\delta[k]$.
V: **(wrong)** I do not know.

Solution 1:

The impulse response $h[k]$ represents the output of the system when the input is a Dirac delta function $\delta[k]$. It characterizes the system's behavior.

Question 152

If $h[\kappa] = 0$ for $\kappa < 0$ and $u[k] = 0$ for $t < 0$, how can the convolution integral $y[k] = \sum_{-\infty}^{+\infty} h[\kappa]u[k-\kappa]$ be simplified?

Potential answers:

I: (**correct**) $y[k] = \sum_{0}^{t} h[\kappa]u[k-\kappa]$

II: (**wrong**) $y[k] = \sum_{0}^{+\infty} h[\kappa]u[k-\kappa]$

III: (**wrong**) $y[k] = \sum_{-\infty}^{+\infty} h[\kappa]u[\kappa]$

IV: (**wrong**) $y[k] = \sum_{-\infty}^{0} h[\kappa]u[k-\kappa]$

V: (**wrong**) I do not know.

Question 153

What is the graphical interpretation of $h[\kappa]$ in the convolution integral $y_{\text{forced}}[k] = \sum_{-\infty}^{+\infty} h[\kappa]u[k-\kappa]$?

Potential answers:

I: **(wrong)** It represents the future inputs of the system.
II: **(correct)** It represents how much past inputs contribute to the current output.
III: **(wrong)** It represents the free evolution of the system.
IV: **(wrong)** It represents the total energy of the system.
V: **(wrong)** I do not know.

Solution 1:

Question 154

What is the primary purpose of using Z-transforms in the context of LTI systems?

Potential answers:

I: **(correct)** To convert convolution in the time domain into multiplication in the Z-domain.
II: **(wrong)** To derive the Laplace transform from the Fourier transform.
III: **(wrong)** To compute the eigenvalues of the system matrix.
IV: **(wrong)** To solve partial differential equations directly.
V: **(wrong)** I do not know

Solution 1:

The primary purpose of using Z-transforms in LTI systems is to simplify the analysis by converting convolution in the time domain into multiplication in the

Question 155

In the ARMA model $y^{[n]} = a_{n-1}y^{[n-1]} + \ldots + a_0 y + b_m u^{[m]} + \ldots + b_0 u$, why is the left-hand side $y^{[n]}$ and not $a_n y^{[n]}$?

Potential answers:

I: **(correct)** To work with monic polynomials, simplifying the analysis.
II: **(wrong)** To ensure the system is always stable.
III: **(wrong)** To make the system nonlinear.
IV: **(wrong)** To reduce the number of initial conditions required.
V: **(wrong)** I do not know

Solution 1:

The left-hand side is $y^{[n]}$ and not $a_n y^{[n]}$ to work with monic polynomials, which simplifies the analysis by reducing the number of coefficients to carry around.

Question 156

What is the purpose of partial fraction decomposition in the context of Z-transforms?

Potential answers:

I: **(correct)** To break down a complex rational function into simpler terms for inverse Z-transform.
II: **(wrong)** To compute the convolution of two signals directly.
III: **(wrong)** To derive the Laplace transform from the Z-transform.
IV: **(wrong)** To solve nonlinear differential equations.
V: **(wrong)** I do not know

Solution 1:

Partial fraction decomposition is used to break down a complex rational function into simpler terms, making it easier to compute the inverse Z-transform, and

Question 157

What are the modes of a LTI system in free evolution?

Potential answers:

I: (**correct**) Combinations of terms like λ^k, $k\lambda^k$, $k^2\lambda^k$, etc.
II: (**wrong**) The eigenvalues of the system matrix.
III: (**wrong**) The coefficients of the ARMA model.
IV: (**wrong**) The initial conditions of the system.
V: (**wrong**) I do not know

Solution 1:

The modes of a LTI system in free evolution are combinations of terms like λ^k, $k\lambda^k$, $k^2\lambda^k$, etc., which describe the natural evolution of the system.

Question 158

How is the forced response of a LTI system computed when $U(z)$ is not rational?

Potential answers:

I: **(correct)** By computing the convolution of the impulse response $h[k]$ with the input $u[k]$.
II: **(wrong)** By using partial fraction decomposition on $U(z)$.
III: **(wrong)** By directly inverting the Z-transform of $U(z)$.
IV: **(wrong)** By solving the system's differential equations numerically.
V: **(wrong)** I do not know

Solution 1:

When $U(z)$ is not rational, the forced response is computed by finding the impulse response $h[k]$ and then convolving it with the input $u[k]$.

Question 159

In the battery charge model $y^+ = y - u$, what does y represent?

Potential answers:

I:	**(wrong)**	The discharge rate of the battery.
II:	**(correct)**	The remaining battery capacity.
III:	**(wrong)**	The temperature of the battery.
IV:	**(wrong)**	The external force applied to the battery.
V:	**(wrong)**	I do not know.

Solution 1:

In the battery charge model, y represents the remaining battery capacity. The equation $y^+ = y - u$ describes how the remaining capacity decreases based on the discharge rate u.

Question 160

What does the separation principle in state-space models imply?

Potential answers:

I: **(<u>wrong</u>)** The system must have an infinite number of states.
II: **(<u>wrong</u>)** The system must be linear.
III: **(<u>correct</u>)** The current state contains all information needed to predict future outputs and states.
IV: **(<u>wrong</u>)** The system must have no inputs or disturbances.
V: **(<u>wrong</u>)** I do not know.

Solution 1:

The separation principle states that the current state $x[k]$ contains all the information necessary to forecast the future evolution of the outputs $y[k]$ and the

Question 161

In the bank account model $x[k+1] = (1 + r[k]) \cdot x[k] + u[k]$, what does $u[k]$ represent?

Potential answers:

I:	**(wrong)**	The interest rate at month k.
II:	**(correct)**	The monthly deposit or withdrawal at month k.
III:	**(wrong)**	The account balance at month k.
IV:	**(wrong)**	The total interest earned at month k.
V:	**(wrong)**	I do not know.

Solution 1:

In the bank account model, $u[k]$ represents the monthly deposit or withdrawal at month k. The state $x[k]$ represents the account balance, and $r[k]$ is the interest

Question 162

In the Lotka-Volterra model, what does the term $\beta y_{\text{prey}} y_{\text{pred}}$ represent?

Potential answers:

I:	**(wrong)**	The natural growth rate of the prey population.
II:	**(wrong)**	The natural death rate of the predator population.
III:	**(correct)**	The interaction between prey and predator populations.
IV:	**(wrong)**	The external disturbance affecting the system.
V:	**(wrong)**	I do not know.

Solution 1:

In the Lotka-Volterra model, the term $\beta y_{\text{prey}} y_{\text{pred}}$ represents the interaction between the prey and predator populations, where β is the predation rate.

Question 163

In the exponential growth model $x^+ = \alpha x + \beta u$, what does α represent?

Potential answers:

I:	**(correct)**	The growth rate of the system.
II:	**(wrong)**	The input to the system.
III:	**(wrong)**	The output of the system.
IV:	**(wrong)**	The disturbance affecting the system.
V:	**(wrong)**	I do not know.

Solution 1:

In the exponential growth model $x^+ = \alpha x + \beta u$, α represents the growth rate of the system, determining how the state x evolves over time.

Question 164

Given the discrete-time ARMA model:

$$y^{+++} + a_2 y^{++} + a_1 y^{+} + a_0 y = b_0 u,$$

what is the correct state-space representation in control canonical form?

Potential answers:

I: (**wrong**)

$$\begin{cases} x_1^+ = -a_2 x_1 - a_1 x_2 - a_0 x_3 + b_0 u \\ x_2^+ = x_1 \\ x_3^+ = x_2 \\ y = x_3 \end{cases}$$

II: (**correct**)

$$\begin{cases} x_1^+ = -a_2 x_1 - a_1 x_2 - a_0 x_3 + u \end{cases}$$

Question 165

For the state-space system:

$$\begin{cases} x_1^+ = -3x_1 + 2x_2 + u \\ x_2^+ = x_1 \\ y = 4x_1 + x_2 \end{cases},$$

what is the equivalent ARMA model?

Potential answers:

I: **(wrong)** $y^{++} + 3y^{+} - 2y = 4u^{+} + u$

II: **(correct)** $y^{++} + 3y^{+} - 2y = u^{+} + 4u$

III: **(wrong)** $y^{++} - 3y^{+} + 2y = u^{+} + 4u$

IV: **(wrong)** $y^{++} + 3y^{+} + 2y = 4u^{+} + u$

V: **(wrong)** I do not know

Question 166

In discrete-time state-space representations, the delay operator z^{-1} primarily:

Potential answers:

I:	**(wrong)**	Approximates continuous-time integration
II:	**(correct)**	Implements the time-shift operation $x[k] \to x[k-1]$
III:	**(wrong)**	Adds stochastic noise to the system
IV:	**(wrong)**	Reduces computational complexity
V:	**(wrong)**	I do not know

Solution 1:

The z^{-1} operator represents a unit delay in discrete-time systems, equivalent to the time-shift operation. This is fundamental for implementing state updates in difference equations.

Question 167

The control canonical form's state matrix A always:

Potential answers:

I:	**(<u>wrong</u>)**	Is diagonal with poles on the diagonal
II:	**(<u>correct</u>)**	Has AR coefficients in its first row and shifted identity below
III:	**(<u>wrong</u>)**	Makes the B matrix identical to $C^{\top}$
IV:	**(<u>wrong</u>)**	Minimizes the number of nonzero elements
V:	**(<u>wrong</u>)**	I do not know

Solution 1:

Control canonical form structures A with $-a_n$ to $-a_0$ in the first row and shifted identity submatrix, ensuring direct mapping from ARMA coefficients. This form guarantees controllability.

Question 168

When converting state-space to ARMA via Z-transform, the operator $(zI - A)^{-1}$:

Potential answers:

I:	**(wrong)**	Directly gives the system's impulse response
II:	**(correct)**	Is the resolvent matrix needed to solve for $X(z)$
III:	**(wrong)**	Always results in a diagonalizable matrix
IV:	**(wrong)**	Can be omitted if $D \neq 0$
V:	**(wrong)**	I do not know

Solution 1:

The resolvent matrix $(zI - A)^{-1}$ is essential for solving $X(z) = (zI - A)^{-1}BU(z)$, which is then used to derive the transfer function $H(z) = C(zI - A)^{-1}B + D$.

Question 169

What does a positive eigenvalue imply about the system's behavior along its corresponding eigenspace?

Potential answers:

I:	(**correct**)	The state grows exponentially along that eigenspace.
II:	(**wrong**)	The state decays exponentially along that eigenspace.
III:	(**wrong**)	The state oscillates along that eigenspace.
IV:	(**wrong**)	The state remains constant along that eigenspace.
V:	(**wrong**)	I do not know.

Solution 1:

A positive eigenvalue implies that the state grows exponentially along the corresponding eigenspace. This is derived from the solution $\boldsymbol{x}[k] = \lambda^k \boldsymbol{x}_0$, where $\lambda > 0$

Question 170

In the context of free evolution of a linear time-invariant (LTI) system, what does the equation $\boldsymbol{x}^{+} = A\boldsymbol{x}$ represent?

Potential answers:

I: **(wrong)** The evolution of the system's output over time.

II: **(correct)** The evolution of the state variables over time, influenced by the system matrix A.

III: **(wrong)** The relationship between input and output signals in the system.

IV: **(wrong)** The response of the system to external inputs.

V: **(wrong)** I do not know

Solution 1:

The equation $\boldsymbol{x}^{+} = A\boldsymbol{x}$ describes the free evolution of the system's state variables

Question 171

Why is it useful to consider the eigendecomposition of the system matrix A in analyzing the free evolution of state variables?

Potential answers:

I: **(wrong)** It simplifies calculating the system's forced response.

II: **(wrong)** It directly determines the output y of the system.

III: **(correct)** It helps identify invariant directions (eigenvectors) and growth/decay rates (eigenvalues) that govern the system's behavior over time.

IV: **(wrong)** It only affects the graphical representation, not the actual system behavior.

V: **(wrong)** I do not know

Solution 1:

Question 172

In a graphical representation, what does the matrix-vector product $A\boldsymbol{x}$ illustrate in the context of system dynamics?

Potential answers:

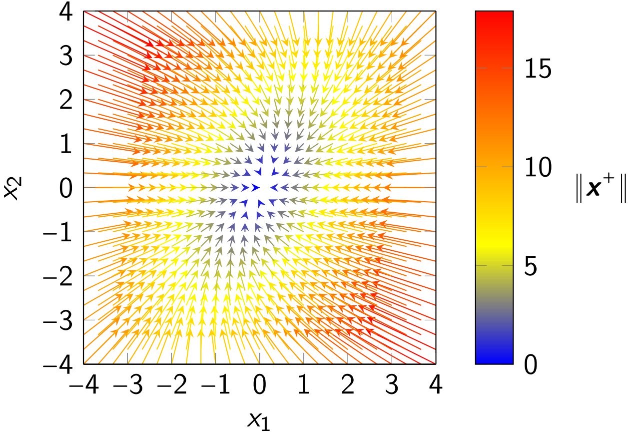
I:	**(wrong)**	The projection of the state vector onto the output space.
II:	**(wrong)**	The response of the system to a unit impulse.
III:	**(correct)**	Where the trajectory of the system is going, starting from $\boldsymbol{x}$.
IV:	**(wrong)**	The change in the input signal over time.
V:	**(wrong)**	I do not know

Solution 1:

The product $A\boldsymbol{x}$ represents $\boldsymbol{x}^{+}$, that indicates the system's dynamics on the state evolution.

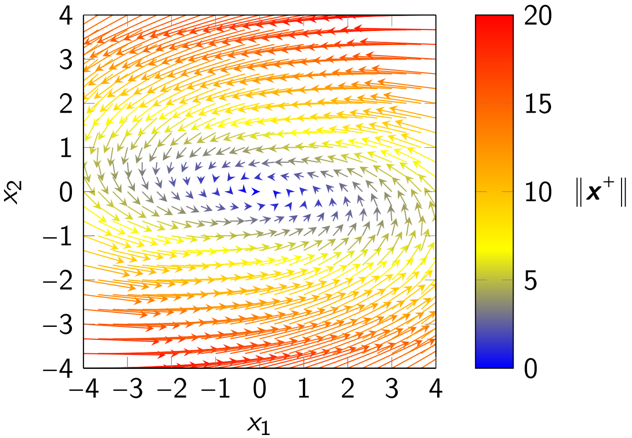
Question 173

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



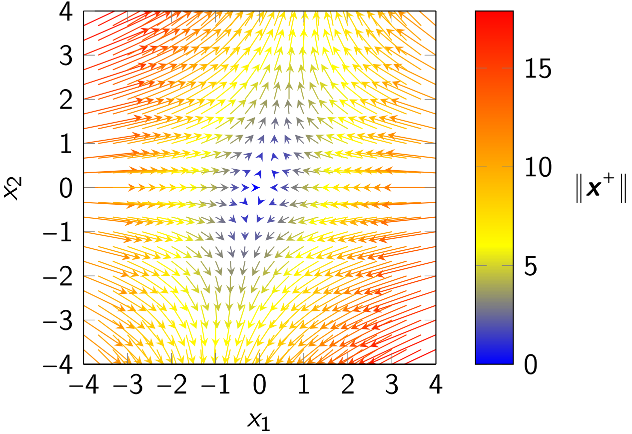
Question 174

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



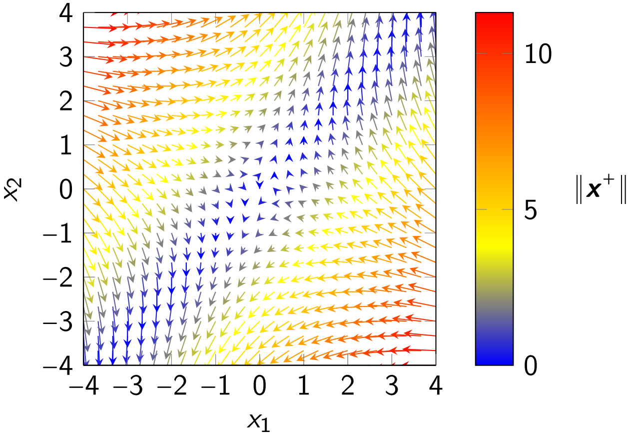
Question 175

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



Question 176

Which eigenvalues and eigenspaces would you say characterize the system matrix A, looking just at this phase portrait?



Question 177

Does the concept of marginal stability of an equilibrium apply only to LTI systems?

Potential answers:

I: **(wrong)** Yes, marginal stability is defined only for LTI systems.
II: **(correct)** No, marginal stability can be defined for nonlinear systems as well.
III: **(wrong)** Marginal stability is irrelevant for LTI systems.
IV: **(wrong)** It only applies to mechanical systems.
V: **(wrong)** I do not know

Solution 1:

Marginal stability is a property that can be analyzed for both LTI and nonlinear systems. While it is often introduced in the context of LTI systems, the concept

Question 178

Does the concept of marginal stability of an equilibrium apply only to continuous-time systems?

Potential answers:

I: **(wrong)** Yes, marginal stability is only defined for continuous-time systems.

II: **(wrong)** No, but it is more relevant in continuous-time systems.

III: **(wrong)** No, discrete-time systems do not have equilibria.

IV: **(correct)** No, marginal stability can be defined for both continuous and discrete-time systems.

V: **(wrong)** I do not know

Solution 1:

Question 179

In the game of marginal stability, who starts? The boss or the apprentice?

Potential answers:

I:	**(wrong)**	The apprentice, since they test small perturbations.
II:	**(correct)**	The boss, since the system dynamics dictate the response.
III:	**(wrong)**	They both start at the same time.
IV:	**(wrong)**	There is no turn-based order in stability analysis.
V:	**(wrong)**	I do not know

Solution 1:

The system dynamics, dictated by the governing equations ("the boss"), determine how the state evolves. The "apprentice" (perturbations) follows.

Question 180

If a system has a marginally stable equilibrium, then all its equilibria must be marginally stable. Is this statement correct?

Potential answers:

I: **(correct)** No, stability properties are equilibrium-dependent.
II: **(wrong)** Yes, if one equilibrium is marginally stable, all others must be as well.
III: **(wrong)** The question is meaningless because marginal stability does not exist.
IV: **(wrong)** Only if the system is conservative.
V: **(wrong)** I do not know

Solution 1:

Question 181

Is the origin for the Lotka-Volterra model simply stable?

Potential answers:

I: **(correct)** No, it is a saddle point and therefore unstable.
II: **(wrong)** Yes, because populations always return to equilibrium.
III: **(wrong)** Yes, because it has only non-positive eigenvalues.
IV: **(wrong)** It depends on the initial conditions.
V: **(wrong)** I do not know

Solution 1:

The origin in the Lotka-Volterra model is typically a saddle point, meaning small perturbations in certain directions grow, making it unstable.

Question 182

Which of the following statements is true regarding the BIBO stability of an LTI system?

Potential answers:

I: **(wrong)** A system is BIBO stable if its impulse response is periodic.
II: **(correct)** A system is BIBO stable if and only if its impulse response is absolutely summable.
III: **(wrong)** A system is BIBO stable if and only if all its eigenvalues have negative real parts.
IV: **(wrong)** A system is BIBO stable if its impulse response is non-negative.
V: **(wrong)** I do not know.

Solution 1:

Question 183

Which of the following impulse responses corresponds to a BIBO stable system?

Potential answers:

I: **(wrong)** $h[k] = e^k$ for $t < 0$, $h[k] = 0$ for $t \geq 0$.

II: **(wrong)** $h[k] = \sin[k]$.

III: **(correct)** $h[k] = e^{-k}\mathrm{step}[k]$, where $\mathrm{step}[k]$ is the unit step function.

IV: **(wrong)** $h[k] = \dfrac{1}{1+k^2}$ for all t.

V: **(wrong)** I do not know.

Solution 1:

The impulse response $h[k] = e^{-k}\mathrm{step}[k]$ is absolutely summable because $\sum^{+\infty} e^{-k} dt = 1$, which is finite, ensuring BIBO stability.

Question 184

A system has an impulse response $h[k]$ such that $\sum_{k=-\infty}^{+\infty} |h[k]| dt$ diverges. What does this imply?

Potential answers:

I:	**(wrong)**	The system is asymptotically stable.
II:	**(correct)**	The system is not BIBO stable.
III:	**(wrong)**	The system has a finite impulse response (FIR).
IV:	**(wrong)**	The system must have at least one pole in the right-half plane.
V:	**(wrong)**	I do not know.

Solution 1:

If the impulse response is not absolutely summable, then the system is not BIBO stable. This means there exist bounded inputs that produce unbounded outputs

Question 185

Consider an LTI system with impulse response $h[k] = \frac{1}{1+t^2}$. What can be said about its BIBO stability?

Potential answers:

I: **(correct)** The system is BIBO stable because its impulse response is absolutely summable.

II: **(wrong)** The system is not BIBO stable because its impulse response is not causal.

III: **(wrong)** The system is not BIBO stable because its impulse response is not exponentially decaying.

IV: **(wrong)** The system is marginally stable.

V: **(wrong)** I do not know.

Solution 1:

Question 186

Which of the following statements correctly describes a BIBO unstable system?

Potential answers:

I: **(wrong)** A BIBO unstable system has a stable impulse response.
II: **(wrong)** A BIBO unstable system has a bounded output for every bounded input.
III: **(wrong)** A BIBO unstable system has a finite impulse response.
IV: **(correct)** A BIBO unstable system has at least one bounded input that produces an unbounded output.
V: **(wrong)** I do not know.

Solution 1:

A BIBO unstable system has at least one bounded input that produces an

Question 187

What is the main downside of applying strong filtering to measurements in a feedback control system?

Potential answers:

I: **(wrong)** It increases the sensor's noise level.
II: **(wrong)** It improves controller robustness without any trade-off.
III: **(correct)** It delays the system response to real changes.
IV: **(wrong)** I do not know

Solution 1:

Strong filtering delays the control systems response to changes, because it attenuates not only noise but also genuine signal variations.

Question 188

Why is it important to filter sensor measurements before using them in a feedback control system?

Potential answers:

I: **(wrong)** To amplify small measurement signals and make the system faster.
II: **(correct)** To reduce the impact of noise that could cause incorrect or overly aggressive control actions.
III: **(wrong)** To completely eliminate all disturbances acting on the system.
IV: **(wrong)** To make the sensor detect only high-frequency changes.
V: **(wrong)** I do not know

Solution 1:

Question 189

What is a potential risk of applying too much filtering to a sensor measurement in a feedback loop?

Potential answers:

I: **(correct)** It can cause the controller to react too slowly to actual changes in the system.
II: **(wrong)** It makes the feedback loop unstable regardless of the controller design.
III: **(wrong)** It increases the sensors precision indefinitely.
IV: **(wrong)** It amplifies the noise rather than reducing it.
V: **(wrong)** I do not know

Solution 1:

Question 190

What happens if noisy sensor measurements are fed directly into a feedback controller without filtering?

Potential answers:

I: **(wrong)** The controller will naturally ignore noise without any additional design efforts.
II: **(correct)** The controller might react unnecessarily to random fluctuations, leading to poor and unstable behavior.
III: **(wrong)** The controller's robustness will automatically improve.
IV: **(wrong)** The sensor will become more accurate over time.
V: **(wrong)** I do not know

Solution 1:

Question 191

Why is a low-pass filter commonly used when pre-processing sensor data for feedback control?

Potential answers:

I: **(<u>correct</u>)** Because it preserves slow, meaningful signal variations while attenuating fast noise components.
II: **(<u>wrong</u>)** Because it completely removes all frequencies, leaving no signal.
III: **(<u>wrong</u>)** Because it amplifies both the noise and the signal for better clarity.
IV: **(<u>wrong</u>)** Because it converts the signal into a perfect step response.
V: **(<u>wrong</u>)** I do not know

Solution 1:

Question 192

Which physical limitation of sensors makes filtering necessary in feedback control systems?

Potential answers:

I: **(wrong)** Sensors can detect changes at infinite speed but need filtering for redundancy.
II: **(correct)** Sensors have finite bandwidth and cannot accurately measure very fast changes.
III: **(wrong)** Sensors generate disturbances intentionally to test the controller.
IV: **(wrong)** Sensors eliminate noise automatically without filtering.
V: **(wrong)** I do not know

Solution 1:

Question 193

Which of the following is **not** a typical performance index when designing a filter for measurement noise?

Potential answers:

I: **(wrong)** Response delay
II: **(wrong)** Noise reduction efficiency
III: **(correct)** System's power consumption in idle mode
IV: **(wrong)** Signal distortion
V: **(wrong)** I do not know

Solution 1:

Power consumption in idle mode is not directly related to filter performance; we usually care about computational load, but idle power is not a filtering perfor-

Question 194

Which performance index primarily measures how much the noise variance is reduced by a filter?

Potential answers:

I:	**(wrong)**	Signal distortion
II:	**(correct)**	Noise reduction efficiency
III:	**(wrong)**	Response delay
IV:	**(wrong)**	Computational cost
V:	**(wrong)**	I do not know

Solution 1:

Noise reduction efficiency measures how much the variance of the noise decreases after filtering. It directly compares the filtered noise to the original noise, quan-

Question 195

In which situation is minimizing signal distortion more important than maximizing noise reduction efficiency?

Potential answers:

I:	**(wrong)**	When measuring low-amplitude environmental data
II:	**(correct)**	When processing audio signals for high-fidelity sound
III:	**(wrong)**	When filtering sensor data in a basic weather station
IV:	**(wrong)**	When removing noise from weak ECG signals
V:	**(wrong)**	I do not know

Solution 1:

In applications like audio signal processing, preserving the integrity of the original signal is critical. Even small distortions can degrade the perceived quality, so

Question 196

What does a filter's phase delay at a given frequency represent?

Potential answers:

I: **(correct)** The amount by which the signal is delayed at that frequency
II: **(wrong)** The amount by which the signal is amplified at that frequency
III: **(wrong)** How much noise remains after filtering
IV: **(wrong)** The robustness of the filter to modeling errors
V: **(wrong)** I do not know

Solution 1:

Phase delay measures how much a filter shifts the phase of a sinusoidal component of the signal at a given frequency. It corresponds to a time delay, which can affect real-time system performance.

Question 197

When is computational cost a particularly critical filter performance consideration?

Potential answers:

I: **(wrong)** In desktop-based data analysis
II: **(correct)** In battery-operated embedded systems
III: **(wrong)** In offline video processing
IV: **(wrong)** In laboratory experiments with high-end equipment
V: **(wrong)** I do not know

Solution 1:

In battery-powered or resource-limited embedded systems, computational cost is crucial because processing power is limited and efficiency directly impacts battery life and system reliability.

Question 198

Which of the following is true regarding filter stability?

Potential answers:

I: **(wrong)** Stability is only important when using filters on high-power computers

II: **(wrong)** Stability can be safely ignored if computational cost is low

III: **(correct)** Stability must always be ensured because instability can cause the output to blow up

IV: **(wrong)** Stability is only relevant for non-linear filters

V: **(wrong)** I do not know

Solution 1:

Stability is critical for all filters. An unstable filter can produce unbounded out-

Question 199

What does a low-pass filter primarily do?

Potential answers:

I: **(wrong)** Amplifies all frequencies equally
II: **(wrong)** Passes high-frequency noise
III: **(correct)** Passes low-frequency signals and attenuates high-frequency noise
IV: **(wrong)** I do not know

Solution 1:

A low-pass filter is designed to keep low-frequency components and reduce high-frequency noise.

Question 200

What characterizes the impulse response of a FIR filter?

Potential answers:

I:	**(wrong)**	It decays exponentially over time
II:	**(correct)**	It is non-zero only for a finite number of time steps
III:	**(wrong)**	It oscillates indefinitely with constant amplitude
IV:	**(wrong)**	It always has exactly one non-zero value
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is that a FIR filter's impulse response is non-zero only for a finite number of time steps. This is the defining characteristic of Finite Impulse Response filters, as shown in the example plot of $h[k]$ in the slides.

Question 201

What is the general form of the transfer function for a FIR filter?

Potential answers:

I:	**(wrong)**	A ratio of two polynomials in z^{-1}
II:	**(correct)**	A polynomial in z^{-1} with no denominator
III:	**(wrong)**	An exponential function of z^{-1}
IV:	**(wrong)**	A logarithmic function of z^{-1}
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is that a FIR filter's transfer function is a polynomial in z^{-1} with no denominator. This is because FIR filters have no feedback terms, which would appear in the denominator.

Question 202

Why do IIR filters require stability analysis while FIR filters don't?

Potential answers:

I:	**(wrong)**	Because IIR filters always have higher gain
II:	**(correct)**	Because IIR filters' impulse response can persist indefinitely
III:	**(wrong)**	Because FIR filters cannot process high frequencies
IV:	**(wrong)**	Because IIR filters are always unstable by design
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is that IIR filters require stability analysis because their impulse response can persist indefinitely (infinite impulse response). FIR filters are inherently stable because their finite impulse response is always absolutely summable.

Question 203

What is the key characteristic of a Butterworth filter's passband?

Potential answers:

I: **(wrong)** It has ripples that help distinguish signals from noise
II: **(correct)** It is maximally flat with no ripples
III: **(wrong)** It automatically adjusts its width based on input frequency
IV: **(wrong)** It only allows exactly one frequency to pass
V: **(wrong)** I do not know

Solution 1:

The correct answer is that a Butterworth filter has a maximally flat passband with no ripples. This is one of its defining characteristics that makes it useful for many applications where signal distortion in the passband needs to be minimized.

Question 204

What happens to a sinusoidal input when processed by a stable LTI system in steady-state?

Potential answers:

I:	**(wrong)**	It gets transformed into a square wave
II:	**(wrong)**	Its frequency changes based on system poles
III:	**(correct)**	It remains sinusoidal with possible amplitude and phase changes
IV:	**(wrong)**	It gets completely attenuated regardless of frequency
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is that the sinusoidal input remains sinusoidal with possible amplitude and phase changes. This is the principle of sinusoidal fidelity - stable

Question 205

Which filter is **least** suitable for removing sparse, large-amplitude outliers?

Potential answers:

I: **(wrong)** Median filter
II: **(wrong)** Butterworth filter
III: **(correct)** Moving average
IV: **(wrong)** Savitzky-Golay filter

Solution 1:

Butterworth filters smooth noise but are linearoutliers "pull" the output. Median filters excel at outlier rejection.

Question 206

Why do we need system identification before applying model-based control techniques like MPC?

Potential answers:

I: **(wrong)** To make the system faster
II: **(wrong)** To reduce noise in sensors
III: **(correct)** To estimate a model of the system from data
IV: **(wrong)** I do not know

Solution 1:

MPC and other model-based controllers require a mathematical model of the system. If we don't have it from physics, we estimate it from data.

Question 207

What is the primary purpose of system identification in control engineering?

Potential answers:

I: **(wrong)** To increase the processing speed of the control system
II: **(correct)** To construct a mathematical model of a dynamic system using data
III: **(wrong)** To eliminate measurement noise entirely from sensors
IV: **(wrong)** To design the controller directly without requiring a model
V: **(wrong)** I do not know

Solution 1:

System identification aims to build mathematical models from input-output data, which are essential for model-based control techniques. Noise reduction and

Question 208

Why is input-output data critical in system identification?

Potential answers:

I: **(wrong)** To determine the physical dimensions of system components

II: **(correct)** To estimate model parameters that best explain the observed behavior

III: **(wrong)** To validate the controller's performance in real-time

IV: **(wrong)** To replace the need for mathematical modeling entirely

V: **(wrong)** I do not know

Solution 1:

Input-output data enables parameter estimation by linking the model's predictions to actual measurements. Physical dimensions and controller validation are

Question 209

What is a major risk of using a poorly identified model in Model Predictive Control (MPC)?

Potential answers:

I: **(wrong)** The system's hardware may suffer physical damage
II: **(correct)** The controller may perform inadequately due to inaccurate predictions
III: **(wrong)** Increased computational load during controller operation
IV: **(wrong)** The need for more frequent sensor calibrations
V: **(wrong)** I do not know

Solution 1:

MPC relies on model predictions for control decisions. A poor model leads to

Question 210

Which three elements are fundamentally required for system identification?

Potential answers:

I: **(wrong)** Actuators, sensors, and a power supply
II: **(wrong)** Controller design, simulation software, and data storage
III: **(correct)** Input-output data, estimation algorithm, and if available, model structure
IV: **(wrong)** Noise filters, feedback loops, and setpoints
V: **(wrong)** I do not know

Solution 1:

System identification requires a model structure to define the mathematical form, input-output data to fit parameters, and an estimation algorithm (e.g., least

Question 211

In the geometric interpretation of least squares, what does the vector $\boldsymbol{y}$ represent?

Potential answers:

I:	**(wrong)**	The model parameters to be estimated
II:	**(correct)**	The fixed vector of measured output values
III:	**(wrong)**	The manifold of all possible model predictions
IV:	**(wrong)**	The noise affecting the measurements
V:	**(wrong)**	I do not know

Solution 1:

In the geometric interpretation, $\boldsymbol{y}$ is the fixed vector of measured output values from the dataset. The least squares problem aims to find the point on the model manifold (determined by $\Phi(\boldsymbol{u})\boldsymbol{\theta}$) that is closest to $\boldsymbol{y}$.

Question 212

What is the fundamental assumption required to derive the normal equations for least squares?

Potential answers:

I:	**(wrong)**	The noise must be Gaussian distributed
II:	**(wrong)**	The model must be nonlinear in parameters
III:	**(correct)**	The problem must be linear in parameters (separable)
IV:	**(wrong)**	The hypothesis space must be constrained
V:	**(wrong)**	I do not know

Solution 1:

The normal equations $\Phi^T \Phi \theta = \Phi^T \boldsymbol{y}$ can only be derived for problems that are linear in their parameters (separable problems). This allows the analytical solution

Question 213

When is the Moore-Penrose pseudoinverse required in least squares problems?

Potential answers:

I:	**(wrong)**	When dealing with nonlinear models
II:	**(wrong)**	When the measurements are noisy
III:	**(correct)**	When $\Phi^T\Phi$ is not invertible
IV:	**(wrong)**	When the hypothesis space is constrained
V:	**(wrong)**	I do not know

Solution 1:

The pseudoinverse is needed when $\Phi^T\Phi$ is singular (not invertible), which occurs when the columns of Φ are linearly dependent. It provides a generalized inverse that gives the minimum-norm solution.

Question 214

What guarantees the existence of a unique least squares solution?

Potential answers:

I:	**(wrong)**	Having more parameters than measurements
II:	**(correct)**	Φ having full column rank and unconstrained parameters
III:	**(wrong)**	The hypothesis space being compact
IV:	**(wrong)**	The noise being normally distributed
V:	**(wrong)**	I do not know

Solution 1:

A unique solution exists when Φ has full column rank (making $\Phi^T\Phi$ invertible) and the parameters are unconstrained. This ensures the normal equations have exactly one solution.

Question 215

What is a key difference between constrained and unconstrained least squares problems?

Potential answers:

I: **(wrong)** Constrained problems always have unique solutions

II: **(correct)** The normal equations may give solutions outside the constraint set

III: **(wrong)** Only unconstrained problems can use the pseudoinverse

IV: **(wrong)** Constrained problems require nonlinear optimization

V: **(wrong)** I do not know

Solution 1:

For constrained problems, the solution from normal equations may violate the

Question 216

Which of the following best describes the difference between an ill-posed and an ill-conditioned problem in system identification?

Potential answers:

I: **(wrong)** Ill-conditioned problems have no solution, while ill-posed problems have too many.

II: **(correct)** Ill-posed problems may lack uniqueness or continuous dependence on the data, while ill-conditioned problems are extremely sensitive to small changes in data.

III: **(wrong)** Ill-posed problems always have unstable solutions, while ill-conditioned ones always diverge.

IV: **(wrong)** Ill-conditioning is due to randomness in the input, while ill-posedness is due to measurement noise.

V: **(wrong)** I do not know

Question 217

Why does the Hunt reconstruction problem become ill-conditioned as the length of the input increases?

Potential answers:

I: **(wrong)** Because more data always makes the system overdetermined.
II: **(correct)** Because slow or non-diverse input signals lead to poor numerical conditioning of the matrix U.
III: **(wrong)** Because increasing the number of samples reduces the noise-to-signal ratio.
IV: **(wrong)** Because the model structure becomes nonlinear with large N.
V: **(wrong)** I do not know

Solution 1:

Question 218

In the context of system identification, what does the condition number $\frac{\sigma_{\max}(U)}{\sigma_{\min}(U)}$ represent?

Potential answers:

I: **(correct)** The maximum amplification of relative errors in the data to the estimation error.
II: **(wrong)** The rate of convergence of the optimization algorithm used.
III: **(wrong)** The ratio between input and output power in the system.
IV: **(wrong)** The likelihood that a model is nonlinear.
V: **(wrong)** I do not know

Solution 1:

The condition number quantifies how sensitive the output of a system (e.g., the

Question 219

What is a practical way to reduce ill-conditioning in system identification?

Potential answers:

I: **(correct)** Use richer or faster-varying input signals during data collection.
II: **(wrong)** Use fewer data points to simplify the estimation problem.
III: **(wrong)** Reduce the noise artificially in the measurements after data collection.
IV: **(wrong)** Make the input signal constant over time to ensure stability.
V: **(wrong)** I do not know

Solution 1:

One way to improve the conditioning of the identification problem is to use an input signal that excites a wide range of system dynamics. This helps ensure the

Question 220

Why is regularization used when solving ill-conditioned system identification problems?

Potential answers:

I: **(wrong)** To make the inverse of U exactly equal to zero.
II: **(correct)** To stabilize the solution by penalizing large parameter values or enforcing smoothness.
III: **(wrong)** To reduce the condition number by artificially shrinking the data.
IV: **(wrong)** To avoid computing the inverse of the matrix altogether.
V: **(wrong)** I do not know

Solution 1:

Regularization introduces additional constraints (e.g., on the norm of the param-

Question 221

What is the primary purpose of regularization in statistical learning?

Potential answers:

I: **(wrong)** To increase model complexity and fit training data perfectly
II: **(correct)** To reduce overfitting by trading some bias for lower variance
III: **(wrong)** To eliminate all bias from the model estimates
IV: **(wrong)** To make computations faster by reducing matrix dimensions
V: **(wrong)** I do not know

Solution 1:

The correct answer is **To reduce overfitting by trading some bias for lower variance**. Regularization intentionally introduces some bias to constrain model complexity, which typically reduces variance and improves generalization perfor-

Question 222

In ridge regression, what Bayesian prior does the L2 penalty term correspond to?

Potential answers:

I:	**(wrong)**	Uniform prior over all parameters
II:	**(wrong)**	Laplace (double exponential) prior
III:	**(correct)**	Gaussian prior centered at zero
IV:	**(wrong)**	Poisson prior with =1
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is **Gaussian prior centered at zero**. The L2 penalty in ridge regression is mathematically equivalent to placing independent Gaussian priors on each parameter, with mean zero and variance determined by the regularization

Question 223

Why does L1 regularization (lasso) tend to produce sparse solutions with exactly zero coefficients?

Potential answers:

I:	**(wrong)**	Because it uses a logarithmic penalty term
II:	**(correct)**	Due to the sharp corners of the L1 constraint region
III:	**(wrong)**	Because it maximizes the likelihood more aggressively
IV:	**(wrong)**	It doesn't - this is a common misconception
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is **Due to the sharp corners of the L1 constraint region**. The geometry of the L1 penalty's diamond-shaped constraint region causes so-

Question 224

What surprising result does the James-Stein estimator demonstrate about maximum likelihood estimation?

Potential answers:

I: **(wrong)** LS estimators always have minimum variance

II: **(correct)** LS can be dominated by shrinkage estimators when estimating multiple parameters

III: **(wrong)** LS becomes biased when sample size exceeds 30

IV: **(wrong)** LS requires normally distributed errors

V: **(wrong)** I do not know

Solution 1:

The correct answer is **LS can be dominated by shrinkage estimators when**

Question 225

When examining a lasso regularization path plot, how should you interpret features whose coefficients become non-zero earliest as decreases?

Potential answers:

I:	**(wrong)**	They are likely measurement errors
II:	**(wrong)**	They should be removed from the model
III:	**(correct)**	They are the most important predictors
IV:	**(wrong)**	They have the smallest scale
V:	**(wrong)**	I do not know

Solution 1:

The correct answer is **They are the most important predictors**. In regularization path plots, features that "enter" the model (become non-zero) at larger

Question 226

In a block diagram representation of a first-order differential equation $\dot{y} = ay + bu$, why does the feedback path emerge?

Potential answers:

I: **(wrong)** Because we need to implement a controller
II: **(correct)** Because the output y affects its own rate of change $\dot{y}$
III: **(wrong)** Because all dynamic systems require feedback
IV: **(wrong)** Because it represents the input signal $u(t)$
V: **(wrong)** I do not know

Solution 1:

The feedback path emerges naturally from the mathematical structure of the differential equation itself. The term ay means the current state y influences its

Question 227

What is the fundamental difference between a branching point and a summing junction in block diagrams?

Potential answers:

I: **(wrong)** Branching points perform calculations while summing junctions don't

II: **(correct)** Branching points duplicate signals while summing junctions combine them

III: **(wrong)** Summing junctions can only handle two inputs while branching points can have many outputs

IV: **(wrong)** Branching points require memory while summing junctions are memoryless

V: **(wrong)** I do not know

Question 228

When reducing a complex block diagram to a single equivalent block, what does the denominator of the resulting transfer function typically represent?

Potential answers:

I: **(wrong)** The gain of the input signal
II: **(wrong)** The time delay of the system
III: **(correct)** The feedback characteristics of the system
IV: **(wrong)** The nonlinearities in the system
V: **(wrong)** I do not know

Solution 1:

The denominator of the reduced transfer function (typically in the form $1 + GH$) captures the system's feedback characteristics. This term determines crucial

Question 229

Why does a dynamic block require memory while a static block doesn't?

Potential answers:

I: **(wrong)** Because dynamic blocks are always digital implementations
II: **(correct)** Because dynamic blocks depend on past values of input/output
III: **(wrong)** Because static blocks can only represent linear relationships
IV: **(wrong)** Because dynamic blocks operate at higher frequencies
V: **(wrong)** I do not know

Solution 1:

The key distinction lies in time-dependence. Static blocks represent instantaneous relationships (output depends only on current input), while dynamic blocks represent relationships where the output depends on the history of inputs/outputs

Question 230

What is the conceptual reason why series-connected blocks can be reduced by multiplying their transfer functions?

Potential answers:

I:	**(wrong)**	Because multiplication is commutative
II:	**(wrong)**	Because it's an arbitrary convention
III:	**(correct)**	Because each block's output becomes the next block's input
IV:	**(wrong)**	Because the Laplace transform requires it
V:	**(wrong)**	I do not know

Solution 1:

The multiplication rule emerges naturally from the series connection structure. The first block's output $G_1(s)X(s)$ becomes the second block's input, which then

Question 231

What is the fundamental limitation of open-loop control compared to closed-loop control?

Potential answers:

I: **(wrong)** It requires more computational power

II: **(correct)** It cannot compensate for unmeasured disturbances or model inaccuracies

III: **(wrong)** It only works for nonlinear systems

IV: **(wrong)** It requires more sensors than closed-loop control

V: **(wrong)** I do not know

Solution 1:

The key limitation of open-loop control is its inability to compensate for distur-

Question 232

Why do we typically linearize nonlinear system models before designing controllers?

Potential answers:

I: **(wrong)** Because all physical systems are fundamentally linear
II: **(wrong)** Because nonlinear controllers cannot be implemented in practice
III: **(correct)** Because most controller design tools and analysis methods are developed for linear systems
IV: **(wrong)** Because linearization increases system stability
V: **(wrong)** I do not know

Solution 1:

We linearize nonlinear models because the vast majority of controller design techniques (including transfer function analysis, frequency response methods, and pole

Question 233

In the car speed control example, why can't perfect disturbance rejection be achieved in practice through open-loop control?

Potential answers:

I: **(wrong)** Because disturbances cannot be measured under any circumstances

II: **(correct)** Because it requires perfect knowledge of both the system model and disturbance characteristics

III: **(wrong)** Because open-loop controllers are inherently unstable

IV: **(wrong)** Because the car's mass changes during operation

V: **(wrong)** I do not know

Solution 1:

Question 234

What is the main practical issue with designing an open-loop controller by perfectly inverting the system model?

Potential answers:

I: **(wrong)** It makes the system too fast

II: **(correct)** It often results in a non-causal controller that requires knowledge of future inputs

III: **(wrong)** It requires solving differential equations in real-time

IV: **(wrong)** It makes the control signal too smooth

V: **(wrong)** I do not know

Solution 1:

Perfect model inversion typically leads to non-causal controllers that would need

Question 235

In the car speed control example, why might choosing a very small time constant in the controller be problematic?

Potential answers:

I: **(wrong)** It would make the controller too simple
II: **(correct)** It would require unrealistically large control forces from the engine
III: **(wrong)** It would make the car accelerate too slowly
IV: **(wrong)** It would prevent the car from reaching the desired speed
V: **(wrong)** I do not know

Solution 1:

A very small (fast response) would demand extremely large control forces because

Question 236

What is the primary conceptual advantage of closed-loop control over open-loop control?

Potential answers:

I:	**(correct)**	Ability to automatically correct errors using feedback
II:	**(wrong)**	Higher computational efficiency in implementation
III:	**(wrong)**	Elimination of all system disturbances
IV:	**(wrong)**	Reduced need for sensors in the system
V:	**(wrong)**	I do not know

Solution 1:

The primary advantage of closed-loop control is its ability to automatically correct errors using feedback. Unlike open-loop systems, closed-loop systems continu-

Question 237

Why are PID controllers so widely used in practice despite their simplicity?

Potential answers:

I: **(<u>wrong</u>)** They can perfectly eliminate all system nonlinearities
II: **(<u>correct</u>)** They provide effective performance across many applications with relatively simple implementation
III: **(<u>wrong</u>)** They require no tuning parameters for optimal performance
IV: **(<u>wrong</u>)** They eliminate the need for system modeling entirely
V: **(<u>wrong</u>)** I do not know

Solution 1:

PID controllers are widely used because they offer effective performance across many applications with relatively simple implementation. The proportional term

Question 238

In the standard closed-loop control notation, what does the transfer function $W_{dy}(s) \approx 0$ imply about the system?

Potential answers:

I:	**(wrong)**	The system cannot track reference signals
II:	**(wrong)**	The controller has become unstable
III:	**(correct)**	The system effectively rejects disturbances
IV:	**(wrong)**	The sensor measurements are inaccurate
V:	**(wrong)**	I do not know

Solution 1:

When $W_{dy}(s) \approx 0$, it means the transfer function from disturbances to output is nearly zero, indicating effective disturbance rejection. This is a desirable property

Question 239

What fundamental limitation prevents a real control system from achieving perfect tracking ($W_{ry}(s) = 1$) and perfect disturbance rejection ($W_{dy}(s) = 0$) simultaneously?

Potential answers:

I: **(wrong)** The need for digital implementation
II: **(wrong)** Sensor accuracy limitations
III: **(correct)** Fundamental trade-offs between performance, robustness, and stability
IV: **(wrong)** The cost of high-quality actuators
V: **(wrong)** I do not know

Solution 1:

The fundamental limitation arises from trade-offs between performance, robust-

Question 240

In the car speed control example with a P controller, what happens to both $W_{ry}(s)$ and $W_{dy}(s)$ as the proportional gain K is increased?

Potential answers:

I: **(wrong)** Both transfer functions approach infinity
II: **(wrong)** $W_{ry}(s)$ approaches 0 while $W_{dy}(s)$ approaches 1
III: **(correct)** $W_{ry}(s)$ approaches 1 while $W_{dy}(s)$ approaches 0
IV: **(wrong)** Both transfer functions become oscillatory
V: **(wrong)** I do not know

Solution 1:

As K increases, $W_{ry}(s) = \dfrac{K}{ms + b + K}$ approaches 1 (better tracking), while

Question 241

What is the first step in designing a PID controller using pole placement?

Potential answers:

I:	**(wrong)**	Tune K_P using trial-and-error
II:	**(wrong)**	Write the plant transfer function in state-space
III:	**(correct)**	Choose desired closed-loop poles based on time-domain specs
IV:	**(wrong)**	Set the integral gain to zero initially

Solution 1:

The first step is to decide where you want the poles to bethis determines the desired system behavior.

Question 242

What is the main goal of pole placement when designing a controller?

Potential answers:

I: **(wrong)** To cancel all poles and zeros of the system
II: **(correct)** To achieve desired time-domain behavior such as settling time and overshoot
III: **(wrong)** To make the transfer function purely algebraic
IV: **(wrong)** To eliminate the need for feedback
V: **(wrong)** I do not know

Solution 1:

Pole placement is used to ensure the closed-loop poles correspond to desired system dynamics, influencing speed, damping, and stability.

Question 243

How does the derivative term (K_D) in a PID controller primarily affect the pole placement of a system?

Potential answers:

- I: **(wrong)** It shifts the system poles toward the imaginary axis
- II: **(wrong)** It always eliminates steady-state error
- III: **(wrong)** It has no influence on the pole placement
- IV: **(correct)** It influences the damping and stability by modifying the characteristic equation
- V: **(wrong)** I do not know

Solution 1:

The derivative term modifies the system's dynamics, particularly by increasing

Question 244

What is the key mathematical operation used to design PID gains through pole placement?

Potential answers:

I: **(wrong)** Taking the inverse Laplace transform of the plant
II: **(wrong)** Eliminating zeros from the open-loop transfer function
III: **(correct)** Matching the closed-loop characteristic polynomial to a desired one
IV: **(wrong)** Factorizing the numerator of the open-loop transfer function
V: **(wrong)** I do not know

Solution 1:

Pole placement design requires expressing the closed-loop characteristic equation

Question 245

In a first-order system controlled by a proportional gain K_P, what is the effect of increasing K_P?

Potential answers:

I: **(correct)** The pole moves further left on the real axis, increasing system speed
II: **(wrong)** The pole becomes complex and causes oscillations
III: **(wrong)** The system gain decreases and response slows down
IV: **(wrong)** The zero of the system moves into the right-half plane
V: **(wrong)** I do not know

Solution 1:

For first-order systems, increasing K_P moves the closed-loop pole leftward (more

Question 246

Which of the following best describes the correct order of steps for PID pole placement design?

Potential answers:

I: **(wrong)** Compute the system output first, then choose PID gains, then set desired poles

II: **(wrong)** Start with experimental PID gains, simulate, and refine based on intuition

III: **(correct)** Choose desired poles, derive the corresponding characteristic polynomial, and match it with the actual closed-loop polynomial to solve for gains

IV: **(wrong)** Eliminate the need for poles by transforming to frequency domain

V: **(wrong)** I do not know

Question 247

What is the primary advantage of state feedback control with pole placement compared to PID control?

Potential answers:

I: **(wrong)** PID control is always more stable than state feedback.
II: **(correct)** State feedback allows arbitrary placement of all closed-loop poles when the system is fully controllable.
III: **(wrong)** State feedback does not require knowledge of the system's state variables.
IV: **(wrong)** PID control can achieve faster response times than state feedback.
V: **(wrong)** I do not know

Solution 1:

Question 248

Why is the control canonical form particularly useful for pole placement problems?

Potential answers:

I: **(wrong)** It makes the system matrix A diagonal.
II: **(wrong)** It eliminates all zeros from the transfer function.
III: **(correct)** The coefficients of the characteristic polynomial appear directly in the first row of A.
IV: **(wrong)** It guarantees that the system will be observable.
V: **(wrong)** I do not know

Solution 1:

The correct answer is that in control canonical form, the coefficients of the characteristic polynomial appear directly in the first row of A. This makes pole place-

Question 249

What is a major practical limitation of aggressive pole placement through state feedback?

Potential answers:

I: **(wrong)** It makes the system uncontrollable.
II: **(correct)** It may require large control inputs that could lead to actuator saturation.
III: **(wrong)** It always makes the system unstable.
IV: **(wrong)** It prevents the use of output feedback.
V: **(wrong)** I do not know

Solution 1:

The correct answer is that aggressive pole placement may require large control

Question 250

When designing state feedback control, why might we choose poles with dominant second-order characteristics?

Potential answers:

I: **(wrong)** Because higher-order systems cannot be controlled effectively.
II: **(wrong)** Because it eliminates all zeros from the system.
III: **(correct)** Because it allows us to approximate the response using familiar second-order performance measures.
IV: **(wrong)** Because it guarantees minimum-phase behavior.
V: **(wrong)** I do not know

Solution 1:

The correct answer is that choosing poles with dominant second-order character-

Question 251

Why is an open-loop estimator generally not considered a robust method for state estimation?

Potential answers:

I: **(wrong)** Because it can track the states accurately even with uncertainties.
II: **(wrong)** Because it uses feedback to correct errors in real time.
III: **(correct)** Because in the presence of model uncertainties or disturbances, the estimation error may diverge.
IV: **(wrong)** Because it relies on noisy measurements, which destabilize the estimation.
V: **(wrong)** I do not know

Solution 1:

Question 252

What determines the stability and speed of convergence of the estimation error $\widetilde{\boldsymbol{x}} = \boldsymbol{x} - \widehat{\boldsymbol{x}}$ in a full-state observer?

Potential answers:

I:	**(wrong)**	The eigenvalues of matrix B.
II:	**(wrong)**	The input $u(t)$ and measurement noise.
III:	**(wrong)**	The initial state $\boldsymbol{x}(0)$.
IV:	**(correct)**	The eigenvalues of the matrix $A - LC$.
V:	**(wrong)**	I do not know

Solution 1:

The dynamics of the estimation error $\widetilde{\boldsymbol{x}}$ are governed by the differential equation $\dot{\widetilde{\boldsymbol{x}}} = (A - LC)\widetilde{\boldsymbol{x}}$. Therefore, the eigenvalues of $A - LC$ determine how the estimation

Question 253

In the observer canonical form, how does the gain matrix L affect the characteristic polynomial of the observer error dynamics?

Potential answers:

I: **(wrong)** It multiplies the coefficients of the system matrix A.
II: **(correct)** It adds to the coefficients of the characteristic polynomial of A.
III: **(wrong)** It replaces the eigenvalues of A with the eigenvalues of B.
IV: **(wrong)** It subtracts from the output matrix C to reduce measurement noise.
V: **(wrong)** I do not know

Solution 1:

Question 254

Why is it generally recommended for the observer poles to be 2 to 6 times faster than the controller poles?

Potential answers:

I: **(wrong)** To ensure the controller has enough time to react to the observer.
II: **(correct)** To make the estimation error dynamics faster than the control system, enabling accurate feedback.
III: **(wrong)** To slow down the observer and reduce noise amplification.
IV: **(wrong)** To match the sampling rate of the digital controller.
V: **(wrong)** I do not know

Solution 1:

Placing the observer poles faster than the controller poles ensures that the esti-

Question 255

What is a trade-off involved when choosing faster poles for the observer?

Potential answers:

I: **(correct)** Faster poles increase sensitivity to measurement noise.
II: **(wrong)** Faster poles always improve estimation accuracy, regardless of noise.
III: **(wrong)** Slower poles make the observer more responsive.
IV: **(wrong)** Faster poles reduce computational complexity.
V: **(wrong)** I do not know

Solution 1:

While faster poles improve the speed of convergence of the observer, they also amplify measurement noise due to higher observer gains. This makes the observer

Question 256

What is the primary effect of increasing the Q matrix in MPC tuning?

Potential answers:

I: **(wrong)** Reduced computational requirements
II: **(wrong)** Smoother control actions
III: **(correct)** Faster state convergence
IV: **(wrong)** Increased robustness to disturbances

Solution 1:

The Q matrix weights the state error, so increasing it prioritizes faster convergence to the desired state.

Question 257

What is the fundamental purpose of the terminal cost (P) in MPC?

Potential answers:

I:	**(wrong)**	To reduce the computational complexity of the optimization
II:	**(correct)**	To ensure stability by approximating infinite horizon behavior
III:	**(wrong)**	To enforce hard constraints on the system states
IV:	**(wrong)**	To prioritize certain states over others in the transient response
V:	**(wrong)**	I do not know

Solution 1:

The terminal cost P is typically chosen as the solution to the algebraic Riccati equation to guarantee stability, effectively approximating the infinite horizon cost-to-go beyond the prediction horizon N.

Question 258

Why might increasing the prediction horizon N improve controller performance?

Potential answers:

I:	**(wrong)**	It allows using larger Q matrices in the cost function
II:	**(correct)**	The controller can account for longer-term system behavior
III:	**(wrong)**	It reduces the need for state constraints
IV:	**(wrong)**	It makes the optimization problem convex
V:	**(wrong)**	I do not know

Solution 1:

A longer prediction horizon enables the controller to "see further ahead" and make better decisions by considering more future states, though this comes at increased computational cost.

Question 259

What is the primary consequence of setting $R = 0$ in the MPC cost function?

Potential answers:

I: **(wrong)** The controller will become unstable
II: **(wrong)** The state constraints will be ignored
III: **(correct)** The controller may use arbitrarily large control inputs
IV: **(wrong)** The prediction horizon becomes irrelevant
V: **(wrong)** I do not know

Solution 1:

The R matrix penalizes control effort. With R=0, the optimizer has no incentive to limit control inputs, potentially leading to aggressive (and possibly impractical) control actions.

Question 260

Which of these represents a fundamental trade-off in MPC tuning?

Potential answers:

I: **(wrong)** Between continuous-time and discrete-time formulations
II: **(wrong)** Between state estimation and control computation
III: **(correct)** Between performance and computational complexity
IV: **(wrong)** Between linear and nonlinear system models
V: **(wrong)** I do not know

Solution 1:

MPC involves balancing control performance (better with longer horizons, more constraints) against computational tractability (worse with these same factors), which is a fundamental design consideration.

Question 261

What is the main advantage of MPC compared to LQR control?

Potential answers:

I: **(wrong)** MPC always requires less computational power
II: **(wrong)** MPC guarantees global optimality for nonlinear systems
III: **(correct)** MPC can explicitly handle state and input constraints
IV: **(wrong)** MPC doesn't require a system model
V: **(wrong)** I do not know

Solution 1:

While both are optimal controllers, MPC's key advantage is its ability to explicitly incorporate and satisfy constraints during the optimization process, which LQR cannot do natively.