I. Physical systems to bond graph
   Mechanical translational & rotational
   free body diagrams
   series elements: 0
   parallel elements: 1
   electrical
   series elements: 1
   parallel elements: 0
   fluidic
II. Power \( P = ef \)
III. Energy \( E = \int P \, dt = \int ef \, dt \)
IV. Bond graph
   elements
   resistance: \( R \)
   energy storage: \( C \) and \( I \)
   links between domains:
   \( GY \): effort to flow, flow to effort
   \( TF \): effort to effort, flow to flow
   sources:
   effort: \( S_e \)
   flow: \( S_f \)
   junctions
   0: common effort, balance of flows
   1: common flow, balance of efforts
   power flows: arrows indicate positive direction
   causality
   assignment via rules of cookbook approach
   integral (desired for energy storage elements)
   independent energy storage (IESE)
   \# IESE determines system order
   derivative (may be forced on some ESE)
   dependent or linked devices
   state equations
   \# St Eqns = \# IESE
   extract from bond graph
   start with IESE
   usually revolves around junctions
   0 => sum flows and/or common effort
   1 => sum efforts and/or common flow
   input bond contribution ALWAYS on LHS
   causal stroke /arrow touching
   only applies to balances
   agree w/input bond => + sign
   disagree w/input bond => - sign
V. System response

Definition of solution: function that renders the differential equation(s) an identity devoid of derivatives.
Also satisfies initial conditions.

Linear system $\dot{x} = Ax + u$

Homogeneous

Postulate $x_{\text{homogeneous}} = a e^{lt}$
Substitute into eqn, get $[l - A]a = 0$
Solve characteristic equation $\det[l - A] = 0$
Get eigenvalues $\lambda_i$
Back substitute $\lambda_i$
$[\lambda_i - A]a_i = 0$
Solve eigenvectors $a_i = [a_{ii}]$

Particular $u(t) = U_0 u_s(t)$
Step, $u_s(t)$
Complete $x_{\text{complete}} = x_{\text{particular}} +$

$\sum_{i=1}^{n} x_{\text{homogeneous}}$

Initial conditions

Apply to complete solution $x_{\text{complete}}$
Determine arbitrary constants

1st order system $\dot{x} + x = h(t)$
General approach (integrate equations)
Time constant $\tau$

2nd order system $\ddot{x} + 2 \zeta \omega_n \dot{x} + \omega_n^2 x = f(t)$
Natural frequency $\omega_n$
Damping ratio $\zeta$
Damped natural frequency $\omega_d = \omega_n \sqrt{1 - \zeta^2}$

Only if $0 \leq \zeta < 1$

Higher order systems

VI. Stability

Eigenvalues

If even one $\text{Re}(\lambda_i) > 0$, $e^{lt}$ becomes large $\Rightarrow$ Unstable
All $\text{Re}(\lambda_i) < 0$, stable
For this exam, know:

1. how to construct a bond graph, given a physical system
2. how to extract state equations from a bond graph
3. how to solve ordinary differential equations
4. the parameters of a $1^{st}$ order system
5. the parameters of a $2^{nd}$ order system