TAMING DR. FRANKENSTEIN: CONTRACT-BASED DESIGN FOR CYBER-PHYSICAL SYSTEMS PT. 2

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PLATFORM-BASED AND CONTRACT-BASED DESIGN

- Platform-based design and contract-based design to formulate the design process with a meet-in-the-middle approach
- Can be considered both horizontal and vertical contracts
- Used “to govern the horizontal composition of the cyber and the physical components and to establish the conditions for correctness of their composition
- It is possible to design a correct-by-construction system

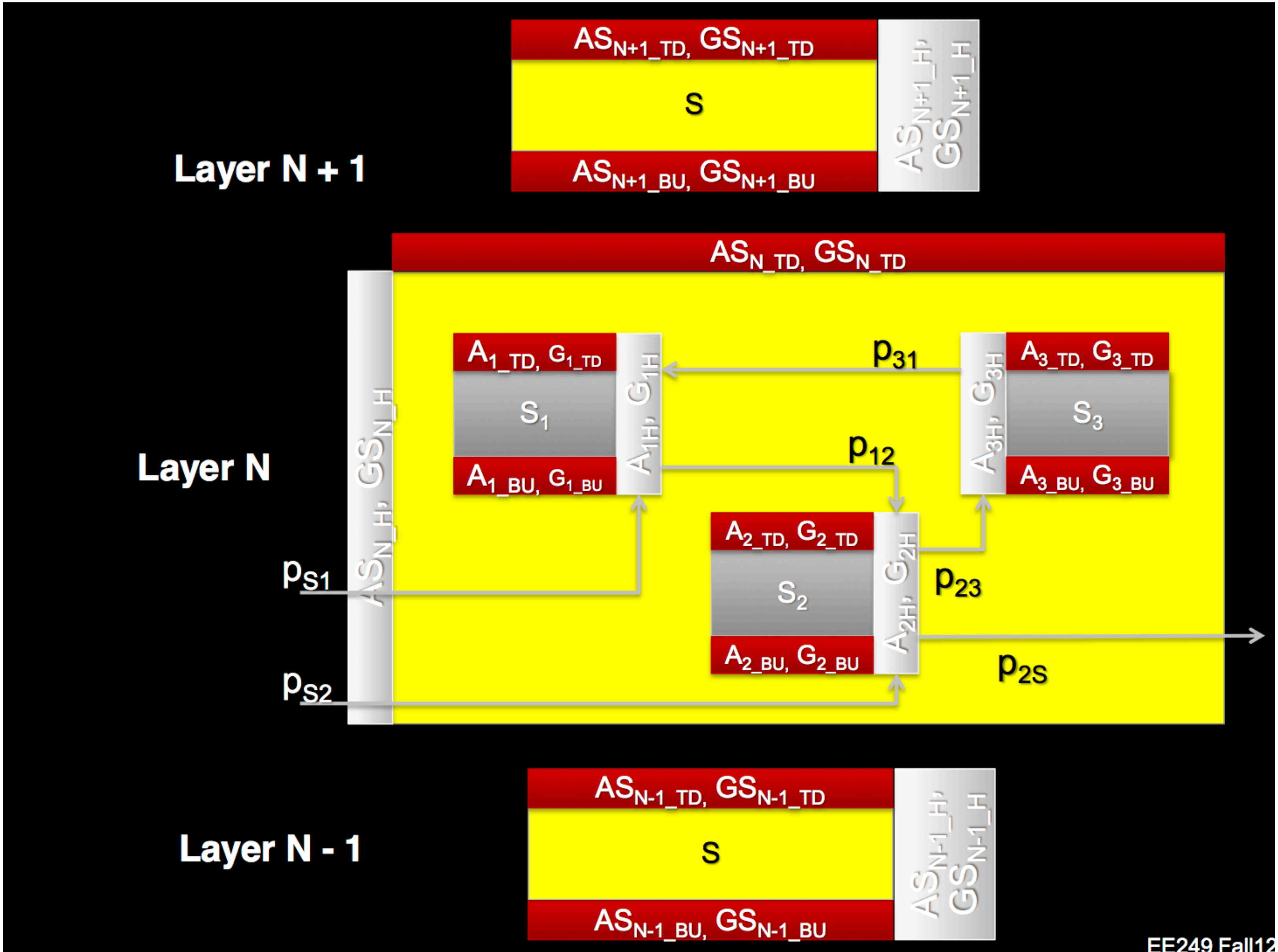
PLATFORM-BASED DESIGN: KEY CONCEPTS

Design through different abstraction layers, each one defined by a design platform.

Each design platform consists of

- A set of library components
- Models of the components in terms of functional and non-functional characteristics
- Rules for the determination of component composition

CONTRACT-BASED DESIGN



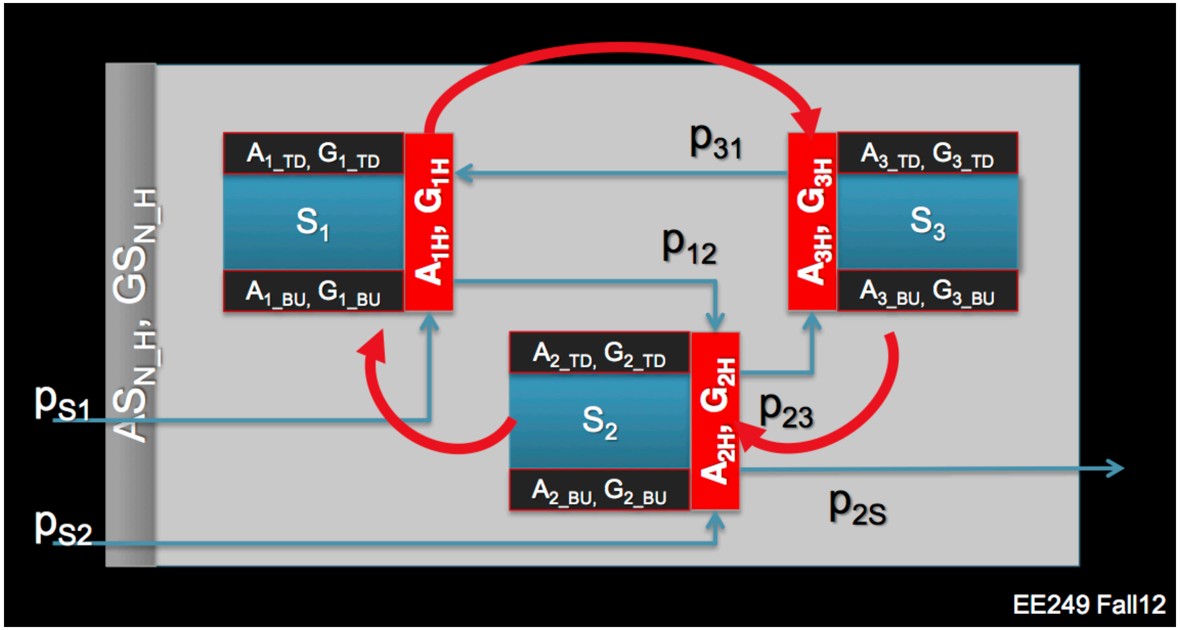
HORIZONTAL CBD

At level N, a set of contracts (1 … j) $\mathcal{C}^H(S_j) = (A_j^H, G_j^H)$

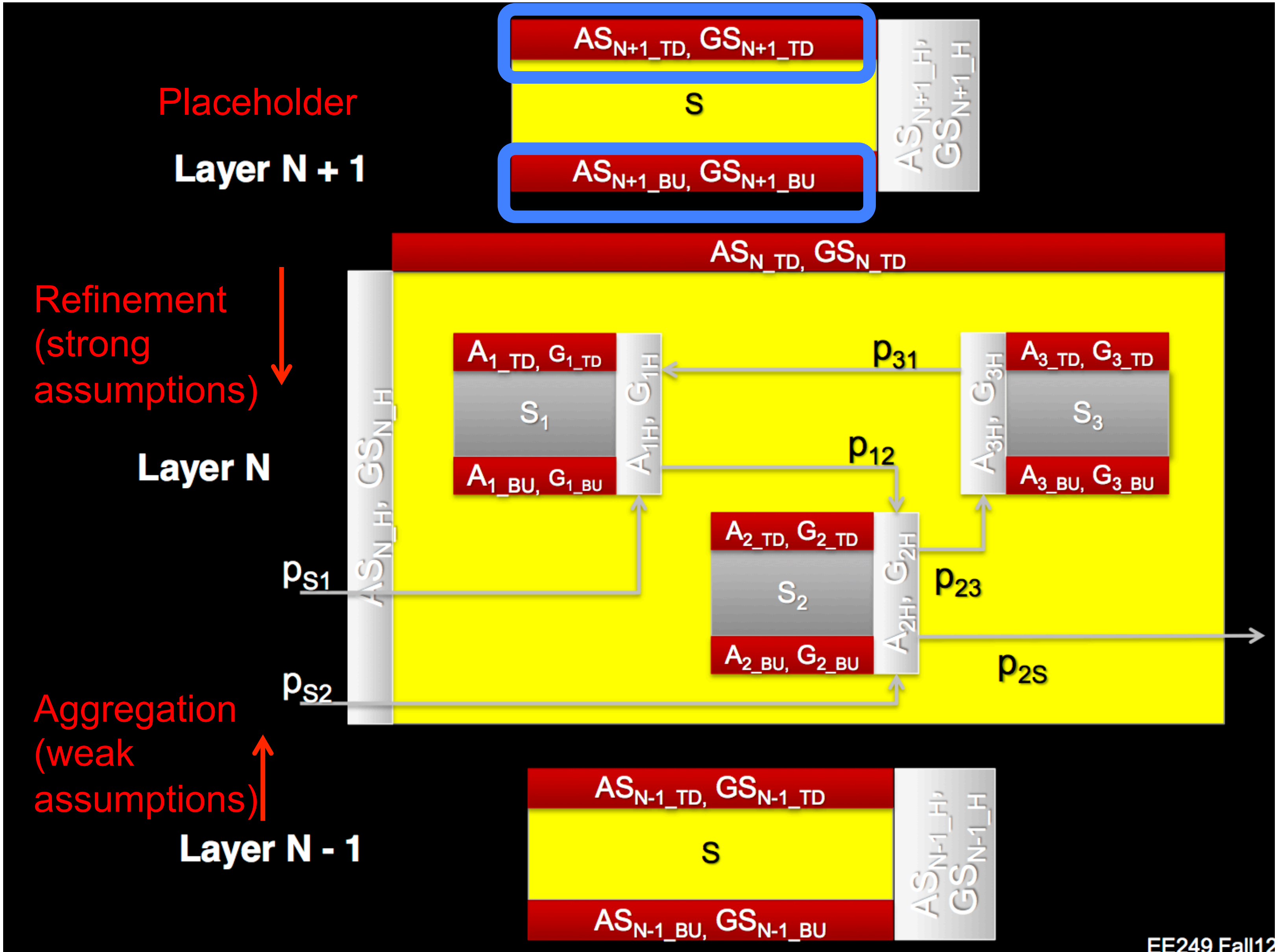
refine a the global contract of the level N

$$\mathcal{C}_N^H(S) = (A_N^H(S), G_N^H(S))$$

Circular reasoning only valid for some classes of contracts (G and A as safety properties)



VERTICAL CBD



CBD EXAMPLE:
A WATER FLOW CONTROL SYSTEM

Problem Information:

- **Input: Inlet pressure P**
- **Output: Water Level wl, outlet flow rate F_{out}, energy consumption E**
- **Parameters: container size D and H, inlet cross sections S_{in} and S_{out}, evaporation rate ε.**

Translated in the global contract:

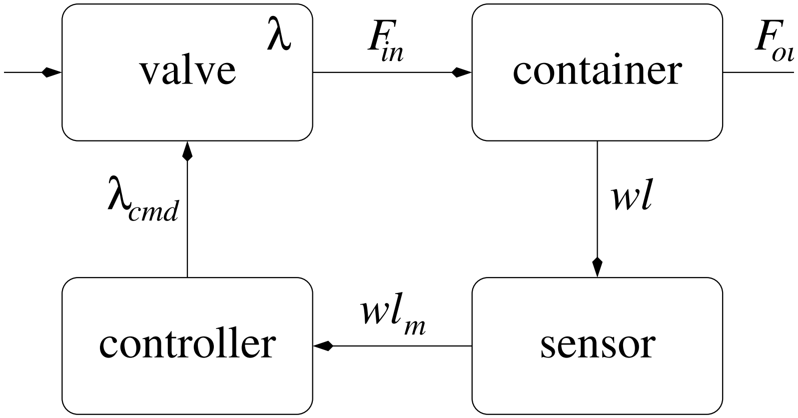
- **Assumption: P>=5000**
- **Promises:** $\forall t.(t \geq 10 \implies (1.0 \leq F_{out} \leq 2.0))$

$$\forall t.(wl(t) \leq H)$$

$$E \leq E_l$$

CBD APPROACH

- Define a contract for each component
- Compose the different contracts
- Verify that the obtained composite contract is a refinement of the global contract



CBD APPROACH

The composite contract is characterized by

- **I/O:** $$I = \{\lambda_{cmd}, F, \varepsilon\}$$ $$O = \{\lambda, F_{in}, wl, F_{out}\}$$
- **Assumption:** $\forall t.\varepsilon(t) \leq 0.25$
- **Promises:**

$$\frac{d\lambda}{dt} = \mathrm{sgn}(\lambda_{cmd}(t) - \lambda(t)) \cdot 0.5$$
$$F_{in} = F \cdot (0.2\lambda^2 + 0.8\lambda)$$
$$\lambda(0) = 0$$
$$\forall t, t'. t' > t \implies wl(t') = wl(t) +$$
$$+ \frac{1}{\pi(D/2)^2} \int_t^{t'} (F_{in}(t'') - F_{out}(t'') - \varepsilon(t''))dt''$$
$$F_{out} = V \cdot S_{out} = \sqrt{2g\, wl} \cdot S_{out}$$

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CBD APPROACH

The composite contract is characterized by

- **I/O:** $I = \{F, \varepsilon\}$
  $O = \{\lambda, \lambda_{cmd}, F_{in}, wl, wl_m, F_{out}, E\}$
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- **Promises:**

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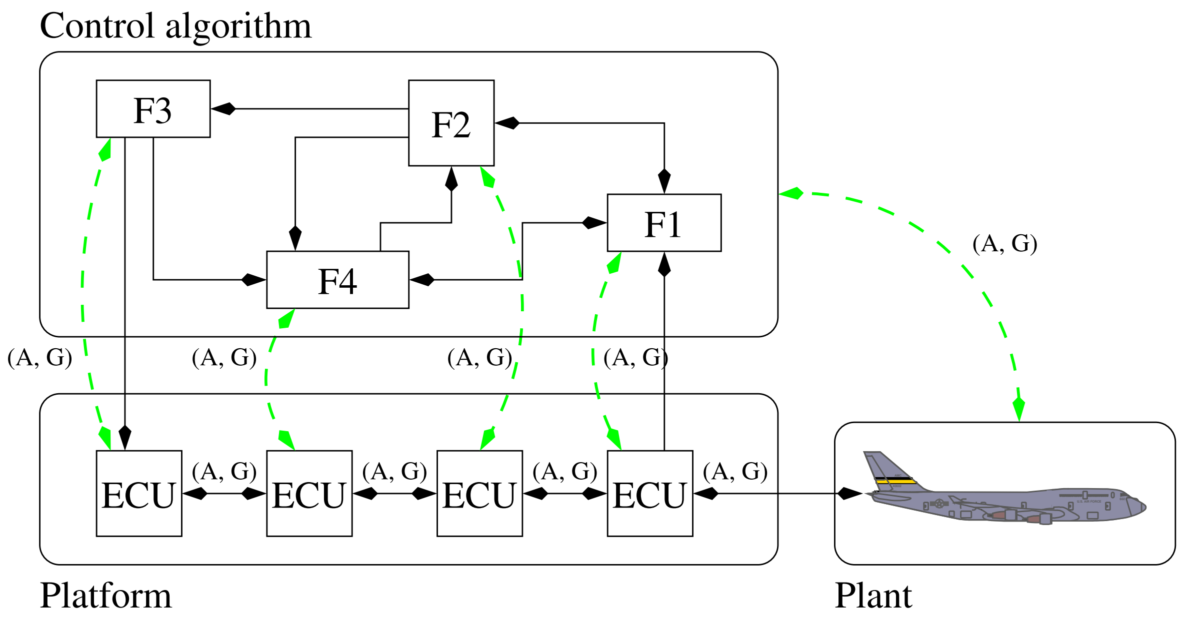
$$\forall t.\, 0.95 \cdot wl(t) \leq wl_m(t) \leq 1.05 \cdot wl(t)$$
$$wl_m \leq wl_{min} \implies \lambda_{cmd} = 1$$
$$wl_m \geq wl_{max} \implies \lambda_{cmd} = 0$$

VERTICAL CONTRACTS IN CONTROL

Controllers are “bounds by contracts to the plant”



CONCLUSION

- **Even in their most elementary form (informal textual requirements) contracts have a considerable methodological value**
- **Can be customized to match particular viewpoints in different design phases (safety, real-time, costs)**
- **Formal definition of contracts allows to think about new tools and frameworks**