Design and testing of Clustered Components for Modular Spacecraft Architectures

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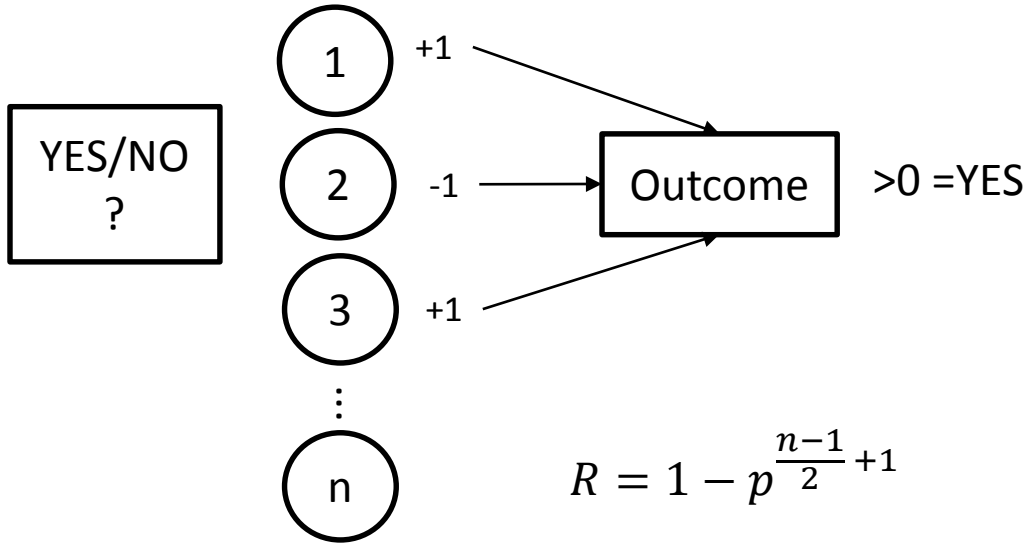
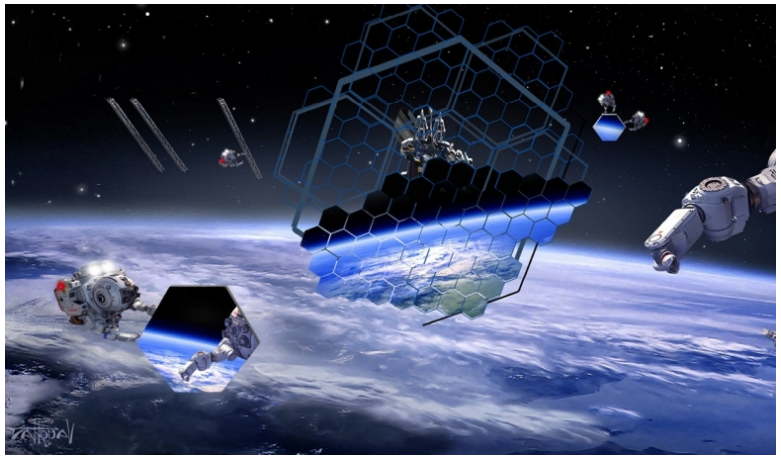
Cluster of components

- Benefits of Clusters:
  - Redundancy breeds Reliability
  - Good Scaling proprieties
  - Economies of scale



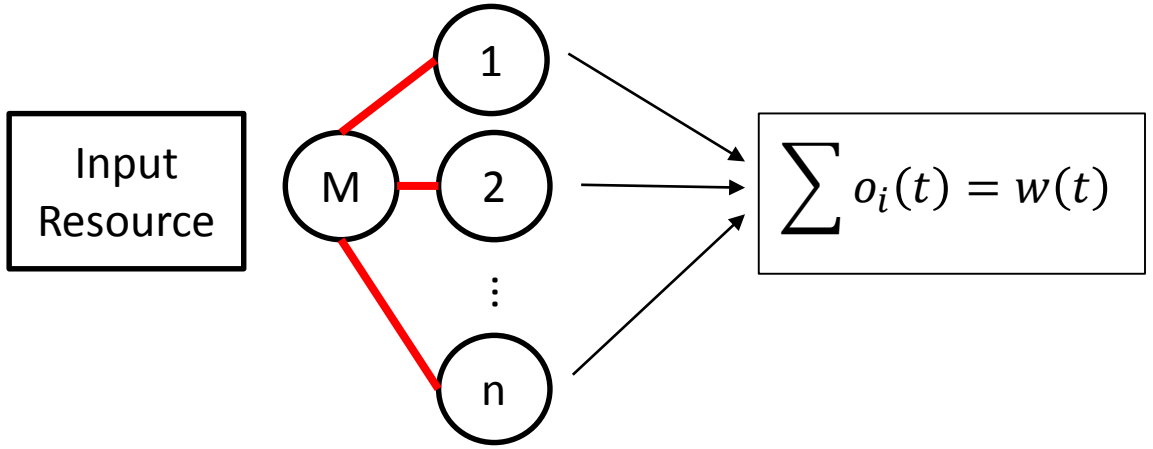
$$R = 1 - p^{\frac{n-1}{2}+1}$$

- They are a byproduct of modular architectures



The *constrained* production problem

A more realistic case is that in which we need a specified amount



- You could dump the excess, but thats a bad idea
- You need to allocate (in some way) total production among the agents
- A Master node is the usual choice, but it is not ideal

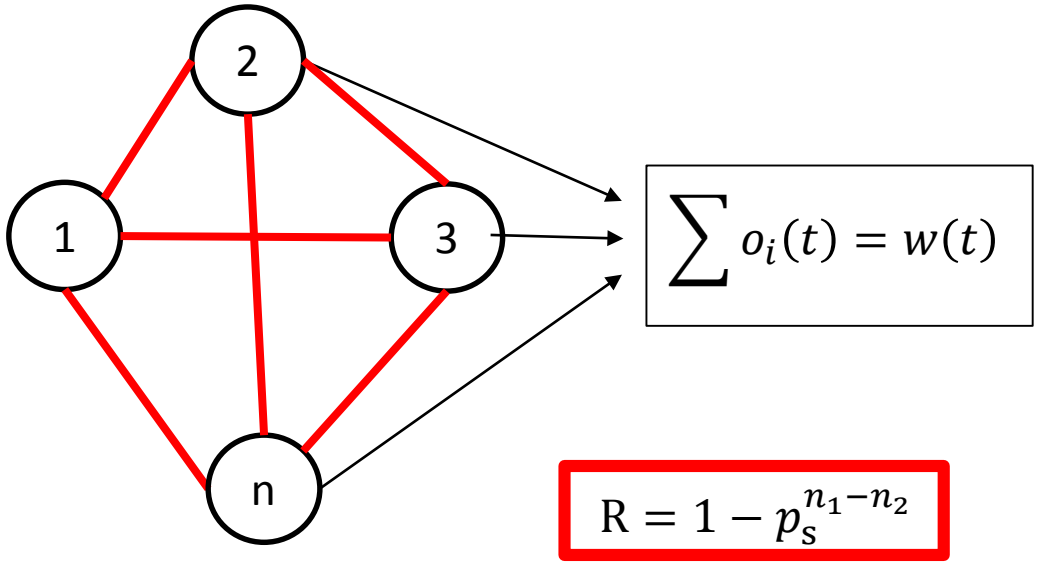
$$R = 1 - p_5^{n_1 - n_2} - p_M$$

$$C = c_0 \cdot n$$

- Failure probability does not go to zero with n large
- Complexity, as the number of bilateral comunication is linear with the number of agents.

Reliability Vs Complexity

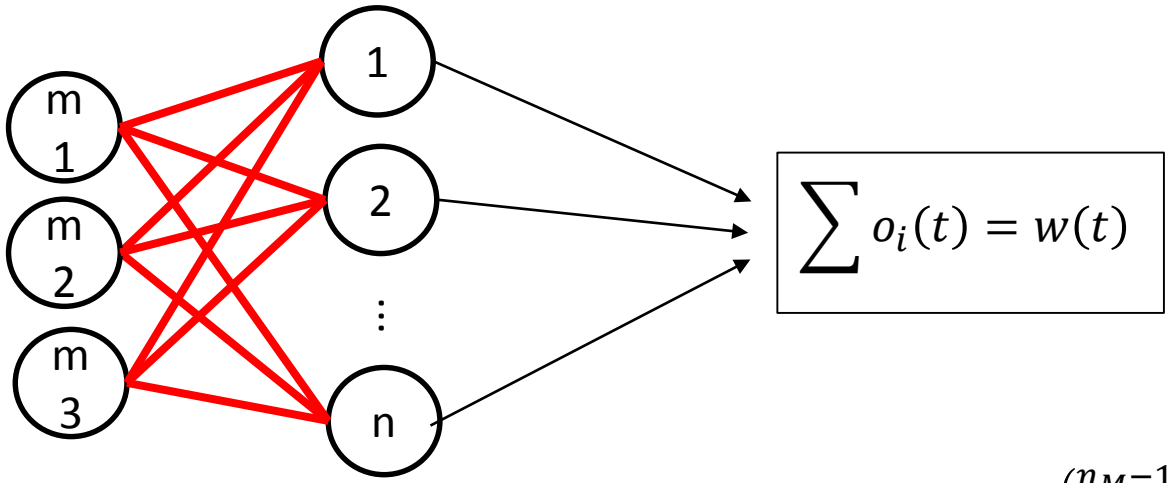
Floating Master



$$R = 1 - p_s^{n_1 - n_2}$$

$$C = \frac{1}{2} n(n-1)$$

Aristocratic model



$$R = 1 - p_s^{n_1 - n_2} - p_M^{\left(\frac{n_M - 1}{2} + 1\right)}$$

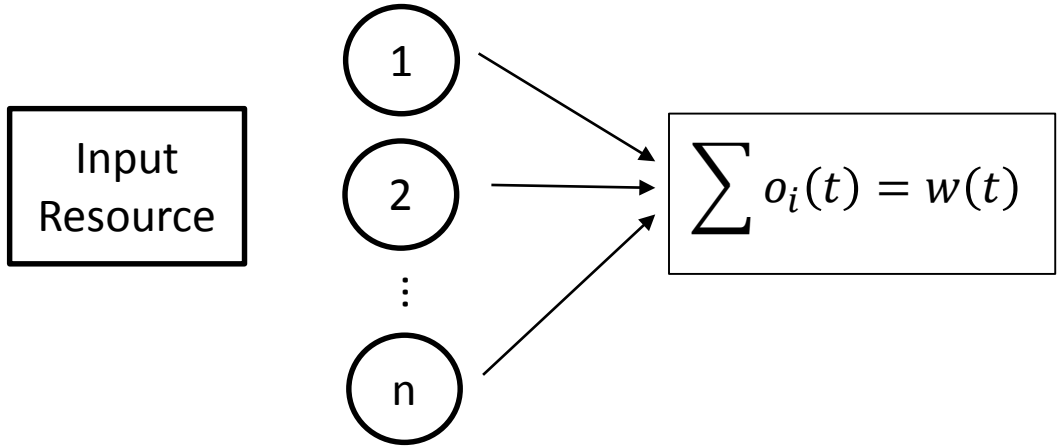
$$C = n_M \cdot n$$

They are worse than the unconstrained problem

Can we use the unconstrained solution?

If we allow no communication among the agents

- Reliability is exponential (with n)
- Complexity is constant (with n)



Can we still meet constrained production?

YES

Outcome of the study of Clusters(so far)

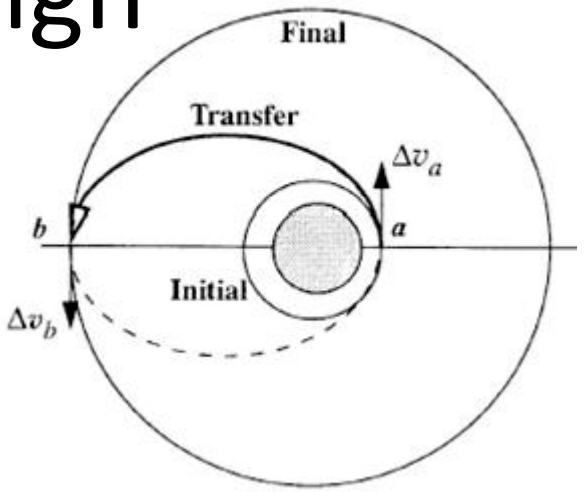
A cluster of components with Completely Distributed Control law provides:

- Exponential reliability
- Active maximization of Cluster efficency
- Simple scaling laws

Accurate scaling laws can significantly improve system design

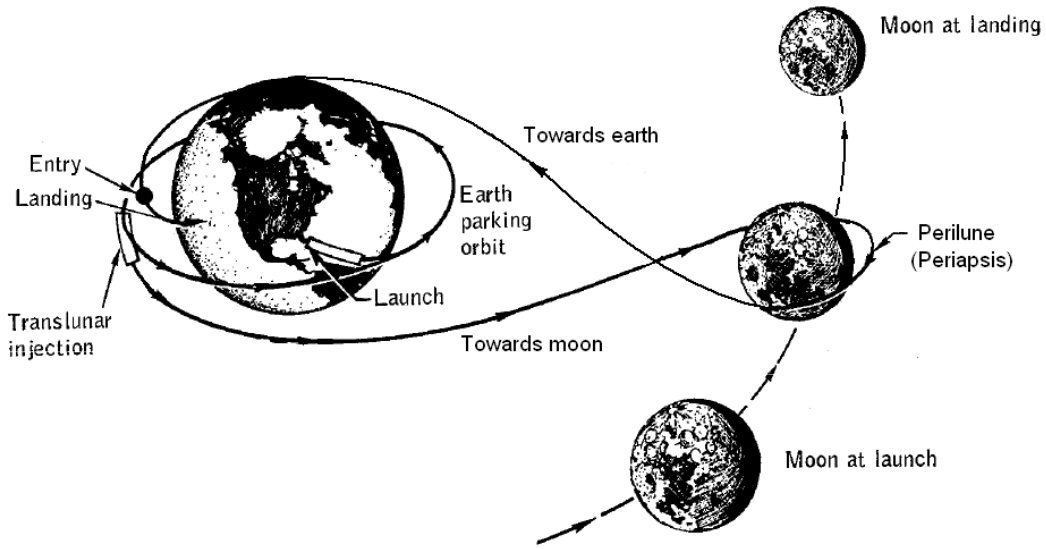
Autonomous System Design

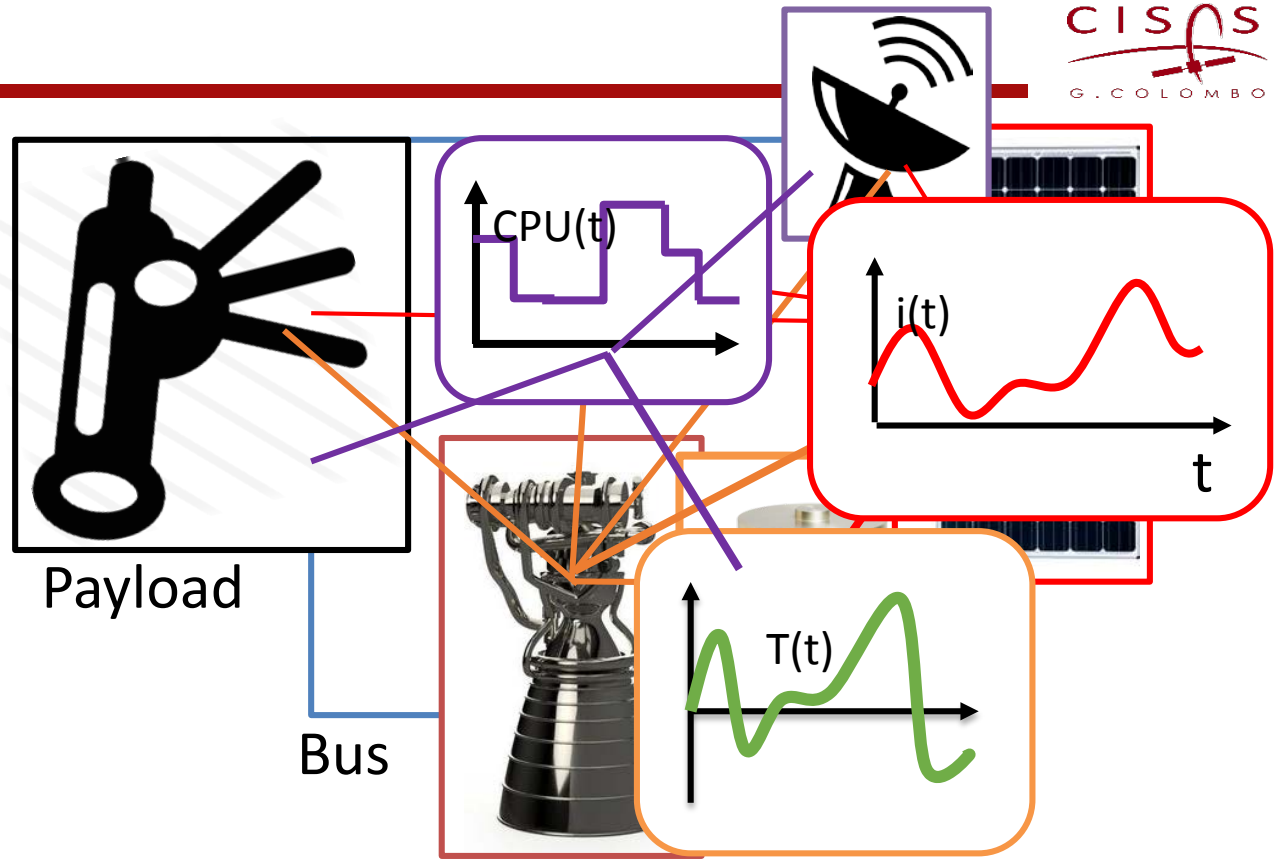
- Given *system independent* mission requirements
- Given the over all architecture



What specifications* do we provide to each subsystem design team?

*In the case of clusters, this means «*How many agents are needed?*»





Mission requirements

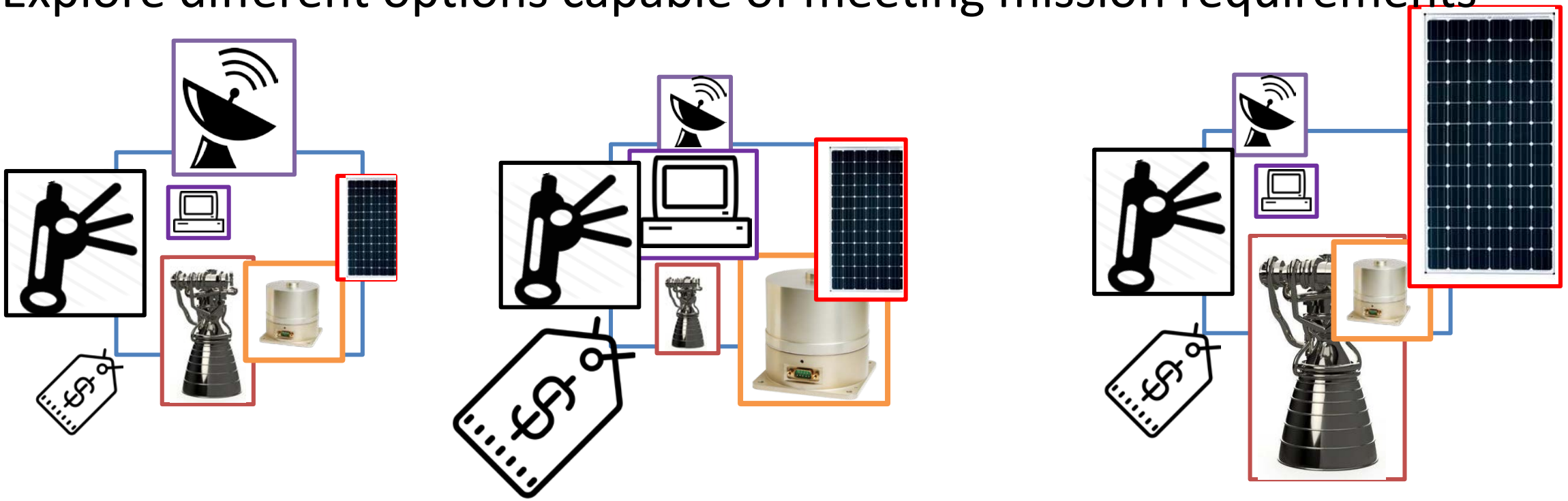
$$r(t)=\begin{pmatrix} \Delta V \\ \ddot{\theta} \\ i_{PL} \\ DL_{PL} \\ CPU_{PL} \\ \dots \end{pmatrix}(t)$$

What are the subsystem requirements?

Total amount of fuel, Minimum impulse resolution, Max Torque, Total angular momentum, Maximum current provided, Battery capacity, Downlink, mass memory storage etc...

System design Process

Explore different options capable of meeting mission requirements



Then you need to define/choose a Cost Function to minimize

Final ideas

But how do you choose a target cost function? How much do you trust it ?

Under known analytical conditions (about the scaling proprieites of the subsystem), it exists an optimal system design which minimizes all cost functions simultaneously, and it is unique.

(The proofs are a rather long)

Thanks!