Towards Generic Design Patterns for Evolvable Modular Architectures

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University of Antwerp

Universiteit Antwerpen

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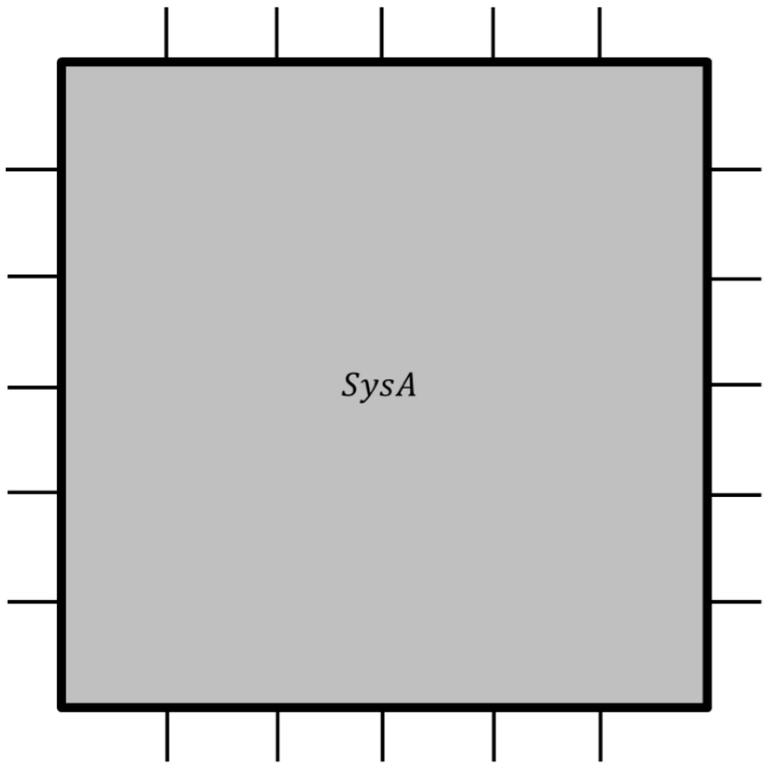
SCIENCES OF THE ARTIFICIAL

Herbert Simon

Sciences of the Artificial

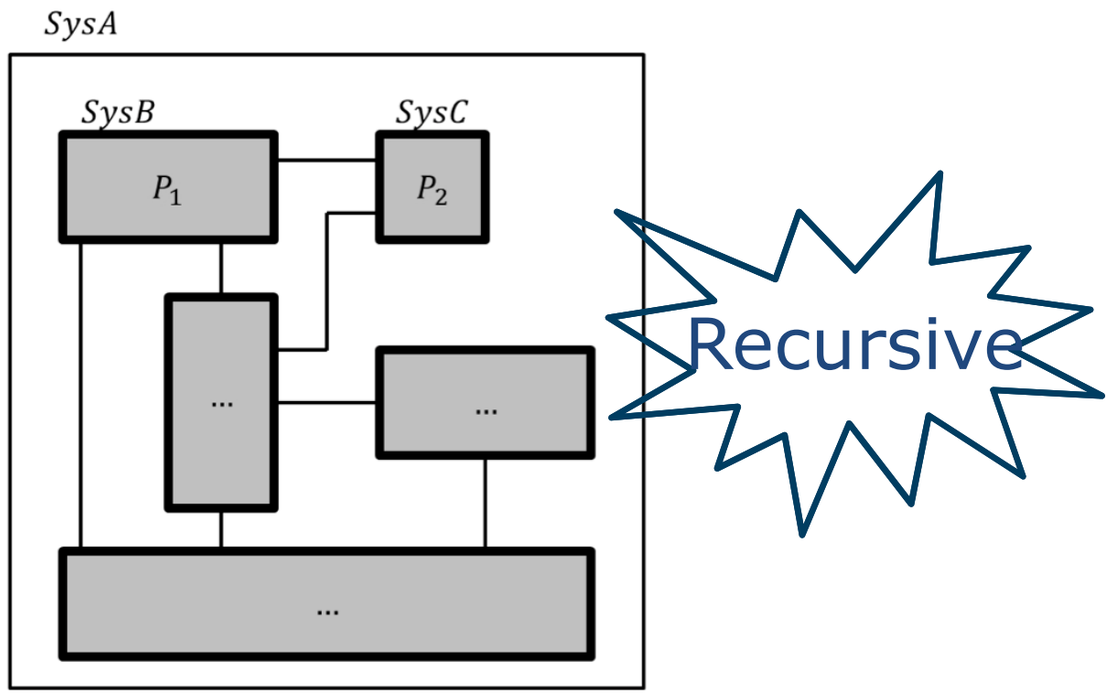
- The architecture of the artificial:

  HIERARCHY

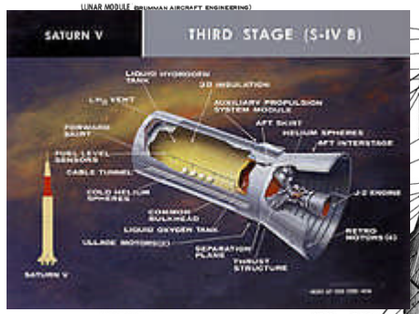


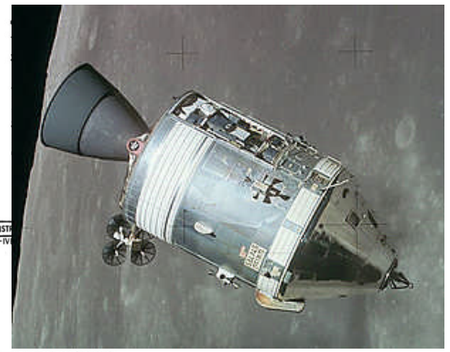
The Architecture: Hierarchy

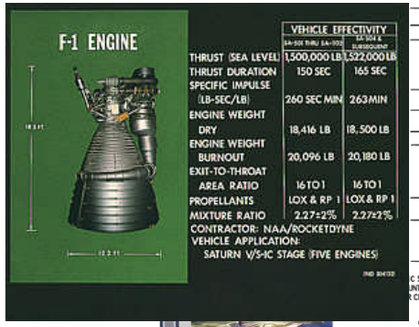
- Interrelated subsystems, hierarchic in structure, until some lowest level of elementary subsystem.

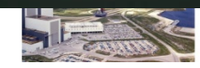


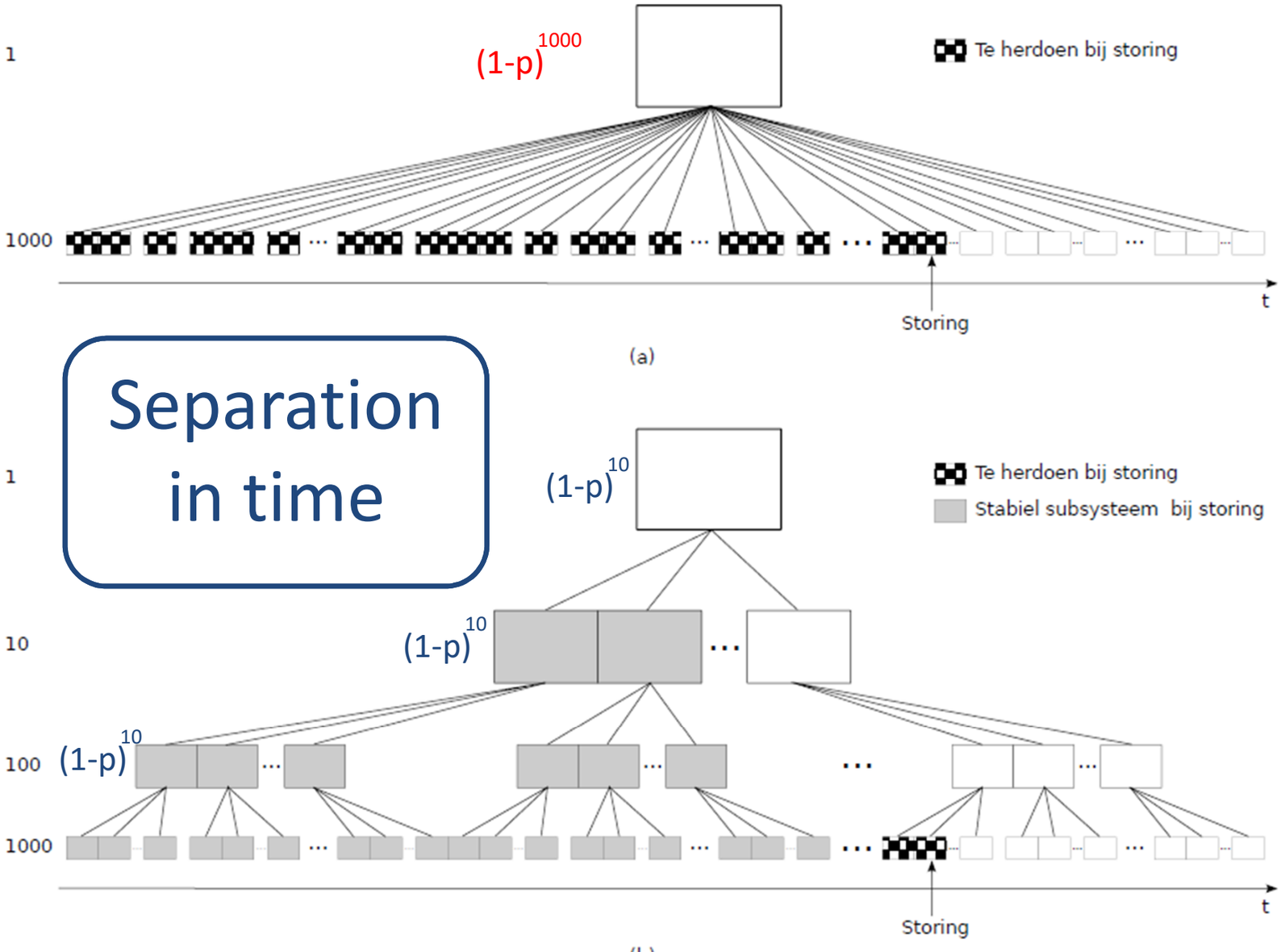
Separation in space










1
(1-p)1000
Te herdoen bij storing
1000
t
Storing
(a)
Separation in time
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Te herdoen bij storing
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t
Storing
(b)

MODULAR SOFTWARE DESIGN

Dave Parnas – Double Dictum

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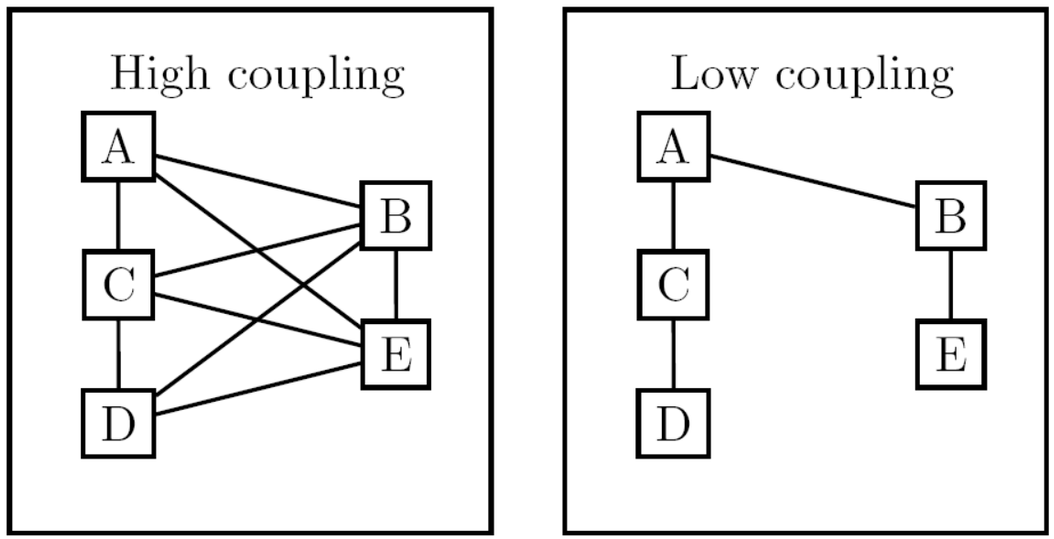
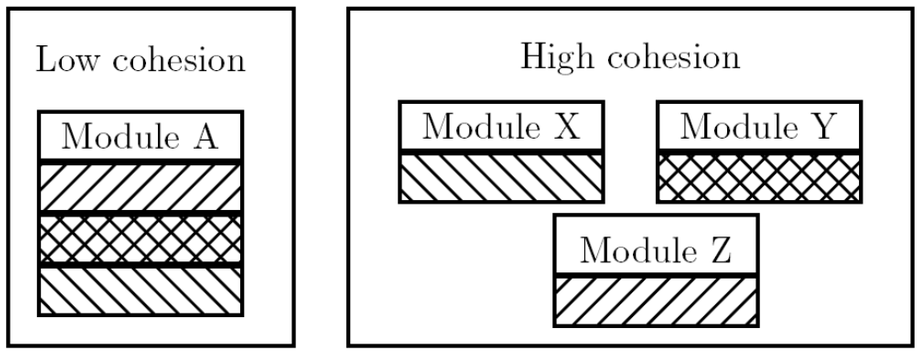
Modules - Coupling

- **Coupling** is a measure of the dependencies between modules



Modules - Cohesion

- **Cohesion** is a measure of how strongly the elements in a module are related



- Good design=

  Low coupling and **high** cohesion!

Modules – advantages

Complexity Reduction

Reuse

Evolvability

THE POWER OF MODULARITY

Carliss Baldwin & Kim Clark

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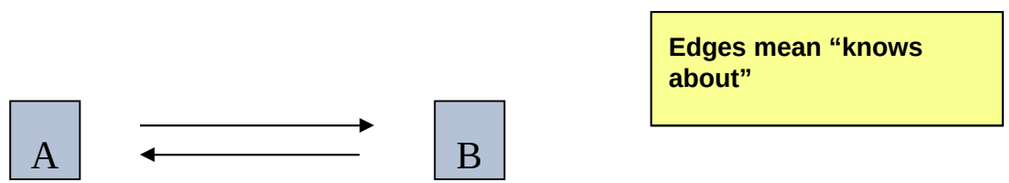
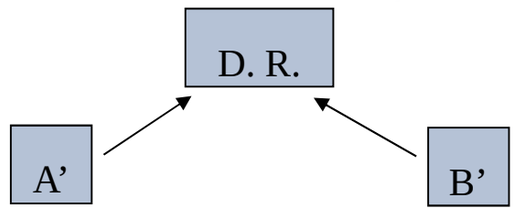
The Modularity Conundrum

- Powerful systems are built of many elements
- Power comes from elements' interplay
- This interplay results in essential interdependences and reduces ability to
  - reuse element w/o others
  - change element w/o changing others



Design Rules

- Idea: have components depend on design parameters guaranteed not to change, called *Design Rules*
- Design rule may be a convention, interface, representation, programming language, etc.
- Design rules are the global, unhidden assumptions; they are the *architecture*
- Chosen properly, elements depend on design rules rather than on each other, becoming true modules



The Value of Modularity

- Modularity not only accommodates change
- It encourages innovation by decentralizing decision making on hidden modules
- Technically, it creates the *option* for third parties to innovate on a module
  - Parties compete to create a better module
  - A few "experiments" likely to create superior module whose value to users exceeds cost of experiments; downside minimal because can keep old
- *Cluster* of innovators emerge around architecture, resulting in new industry

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SEPARATING MODULES

On Exponential Variation Gains

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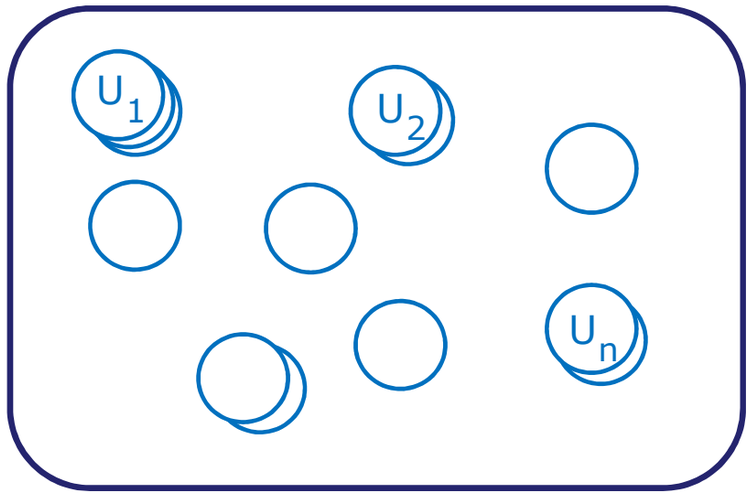
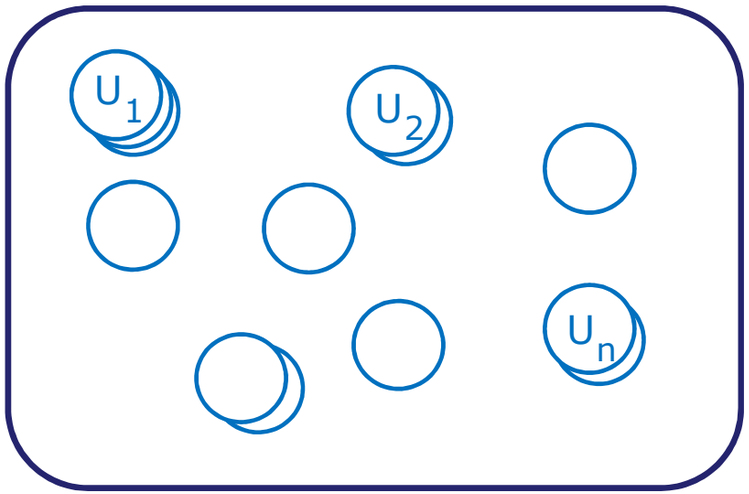
Systems and Processes

- a software program
- a chair manufacturing
- a car assembly process
- a study/training program
- a business process flow
- a cough syrup production
- …

Emerging Units and Variants

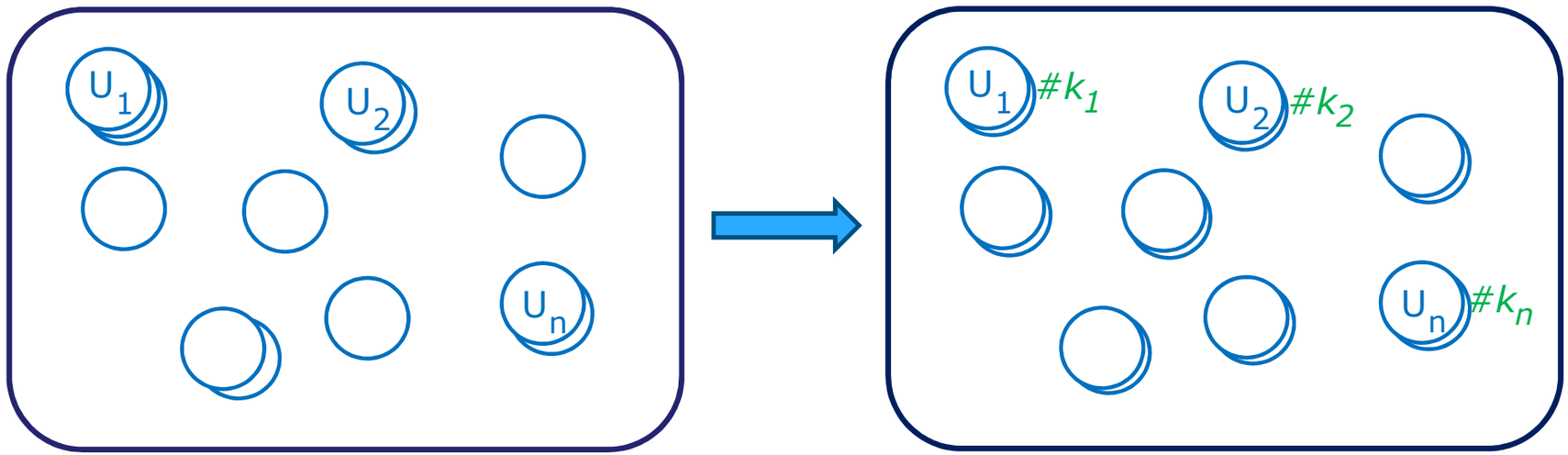


Emerging Units and Variants



- a software program
  - logic units of work
  - computation variants
- a chair manufacturing
  - chair parts
  - variants of parts
- a car assembly process
  - mounting parts
  - versions and options
- a study/training program
  - course modules
  - majors/electives
- a business process flow
  - tasks or activities
  - various rules
- a cough syrup production
  - ingredients syrup
  - various fever relievers
- …

Global Module: Config Glue

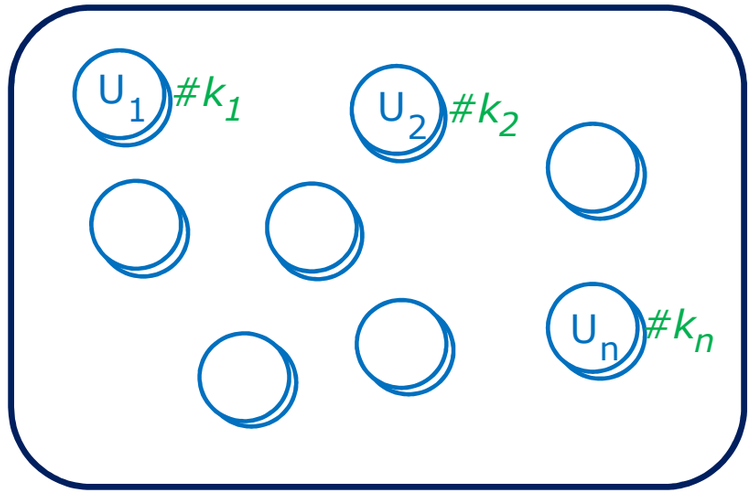


Unit versions: $\sum_{i=1}^{N} k_i$

Glue logic

Global Module: Config Glue

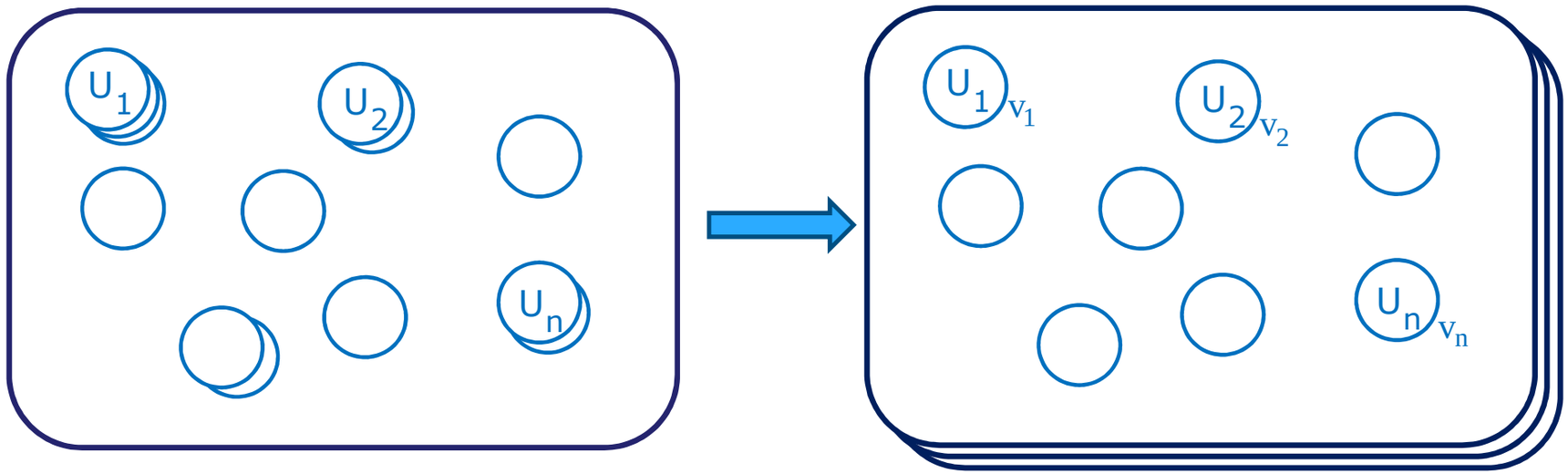
- a complex program
  - all variants of all units
  - selection logic
- a chair manufacturing
  - all part versions
  - selection in process
- a car assembly process
  - all variants of all parts
  - selection and steering
- a study/training program
  - all course part versions
  - choosing in process
- a business process flow
  - all versions of all tasks
  - evaluation and selection
- a cough syrup production
  - ingredient variants
  - selection and steering
- …



Unit versions: $\sum_{i=1}^{N} k_i$

Glue logic

Global Module: Config Variants

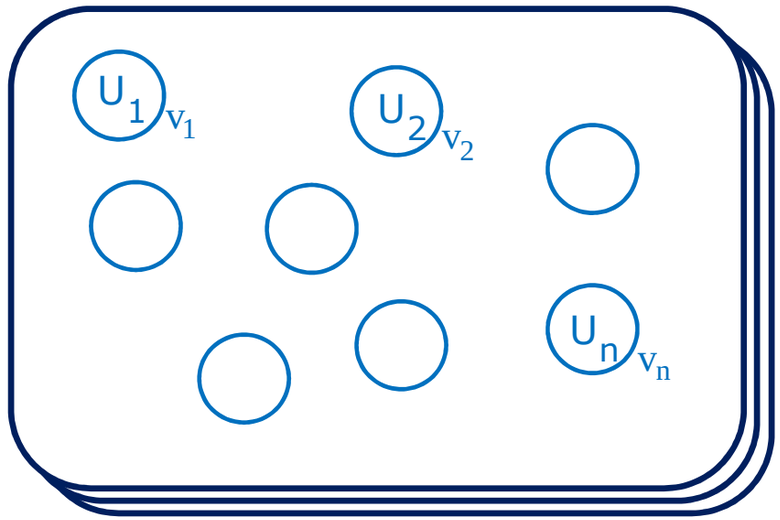


Unit versions: $\sum_{i=1}^{N} k_i$

Module versions: $\prod_{i=1}^{N} k_i$

Global Module: Config Variants

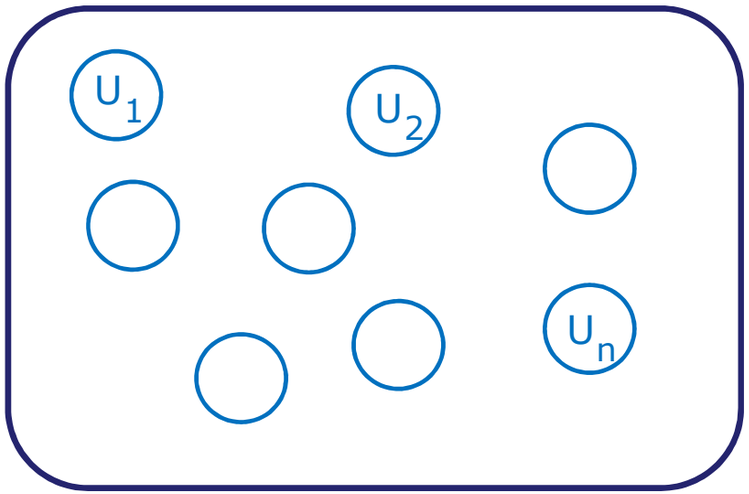
- a dedicated program
  - for every input set
  - input configurator
- a chair manufacturing
  - for every chair type
  - Routing configurator
- a car assembly process
  - for every possible car
  - routing configurator
- a study/training program
  - for every unique program
  - input configurator
- a business process flow
  - for every possible path
  - input configurator
- a cough syrup production
  - for every composition
  - routing configurator
- …



Unit versions: $\sum_{i=1}^{N} k_i$

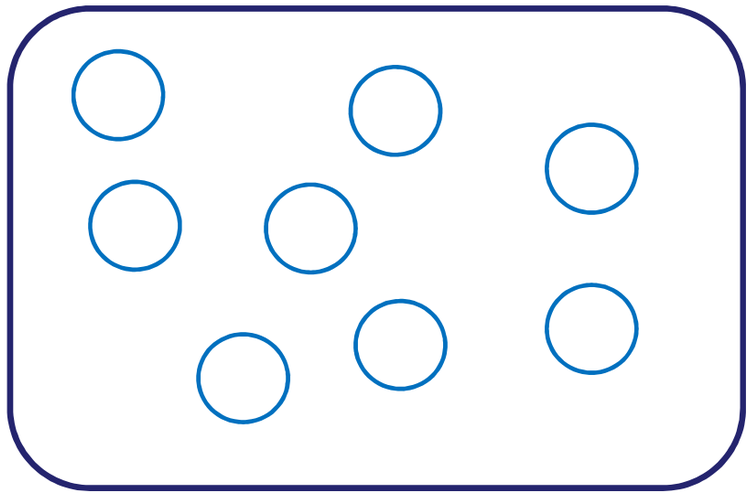
Module versions: $\prod_{i=1}^{N} k_i$

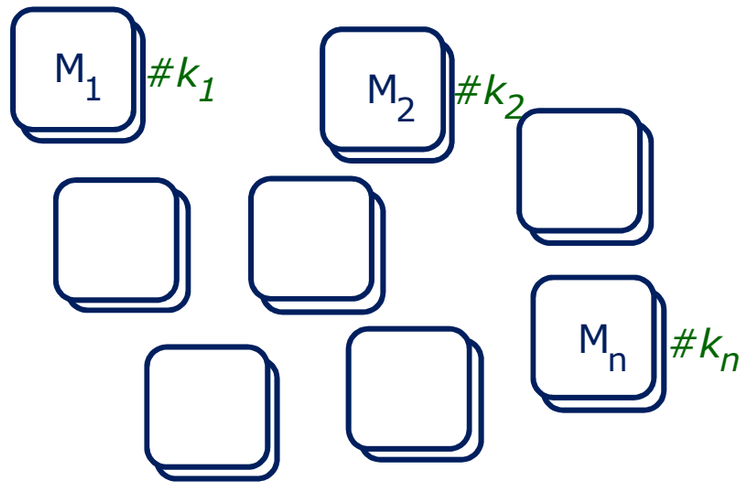
Emerging Units and Variants



- a software program:
  - logic units of work
  - computation variants
- a chair manufacturing
  - chair parts
  - variants of parts
- a car assembly process
  - mounting parts
  - versions and options
- a study/training program
  - course modules
  - majors/electives
- a business process flow
  - tasks or activities
  - various rules
- a cough syrup production
  - ingredients syrup
  - various fever relievers
- …

Emerging Cohesive Modules



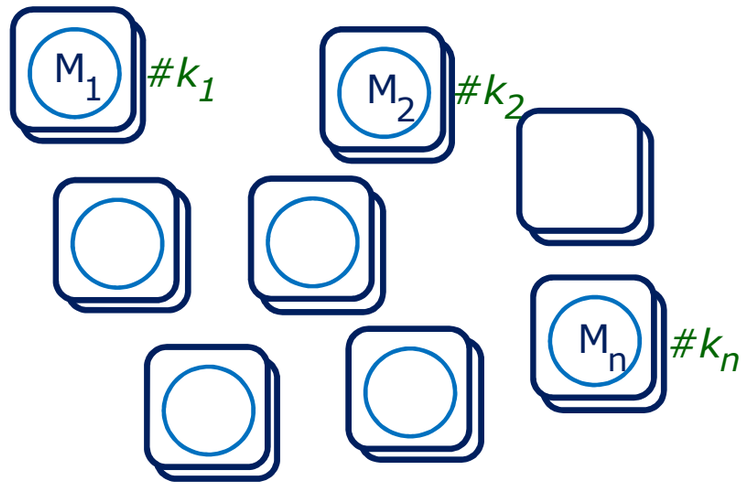


Module versions: $\sum_{i=1}^{N} k_i$

System variants: $\prod_{i=1}^{N} k_i$

Cohesive Modules

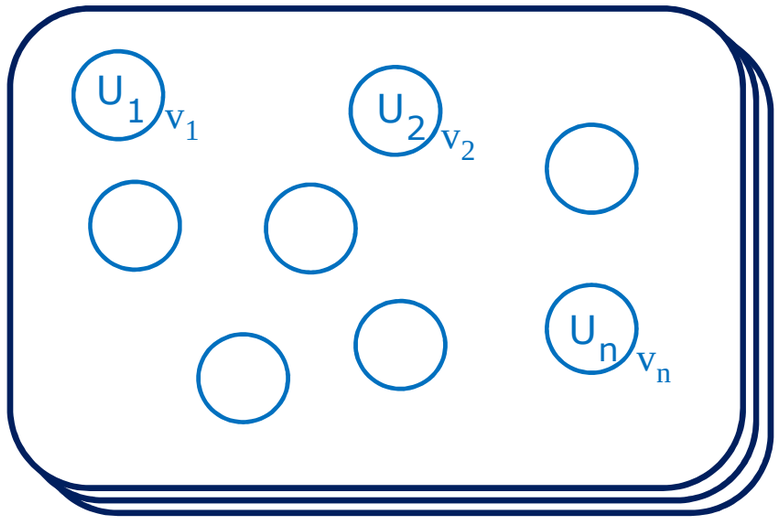
- a set of modules
  - for every unit of work
  - with various versions
- chair manufacturing units
  - for every chair part
  - with various options
- car assembly process units
  - for every car part
  - with various part variants
- study/training modules
  - for every course module
  - with various options
- business activity modules
  - for every possible task
  - with various options
- syrup ingredient units
  - for every ingredient
  - with various flavours
- …

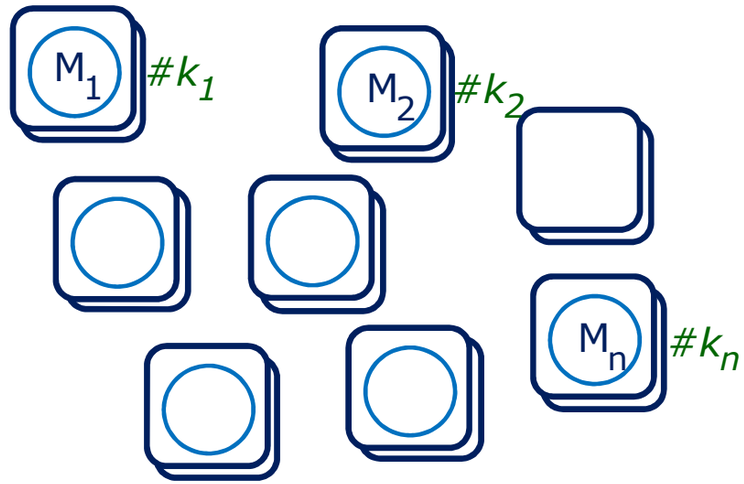


Module versions: $\sum_{i=1}^{N} k_i$

System variants: $\prod_{i=1}^{N} k_i$

Combinatorics of Modularity





Module versions: $\prod_{i=1}^{N} k_i$

System variants: $\prod_{i=1}^{N} k_i$

Module versions: $\sum_{i=1}^{N} k_i$

System variants: $\prod_{i=1}^{N} k_i$

Exponential Variation Gains

The Dream: Doug Mc Ilroy

"expect families of routines to be constructed on *rational principles* so that families fit together as **building blocks.** In short, [the user] should be able safely to regard components as black boxes.**"**

uit: McIlroy, *Mass Produced Software Components*,
1968 NATO Conference on Software Engineering, Garmisch, Germany.

Framework Combinatorics

Concern type	*Multiplicity*	*Implementations*
Database	4	Postgres, HSQL, SQLServer, MySQL
Persistency	2	OpenJPA, Hibernate
Transaction	2	EJB2, EJB3
Remoting	2	RMI, WS
Controller	3	Cocoon, Struts2, Struts2-Knockout
Styling	2	Bootstrap, Plain
Access	2	JavaEE, NS

Module versions: $\sum_{i=1}^{N} k_i$ *System variants:* $\prod_{i=1}^{N} k_i$

AGGREGATING MODULES

On Exponential Ripple Costs

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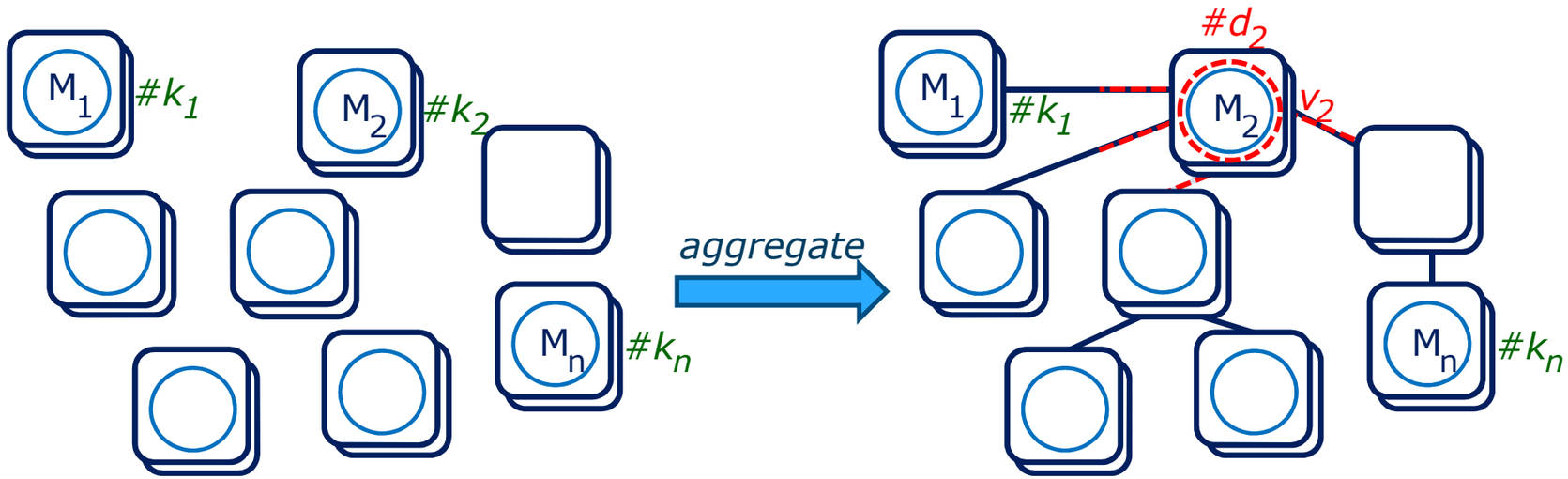
Combinatorics of Coupling



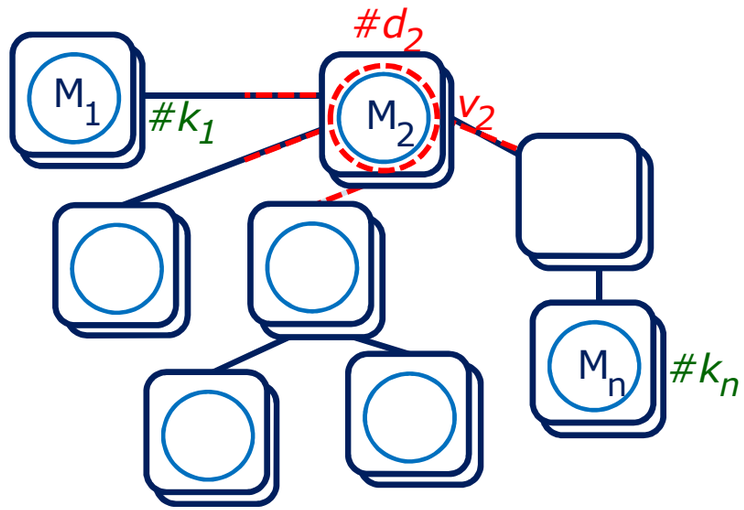
Potential 1st impact: $\sum_{j=0}^{d_i} k_j$

Potential 2nd impact: $\sum_{j=0}^{d_i} \left[\sum_{l=0}^{d_j} k_l \right]$

Change: Exponential Ripple Costs

Combinatorics of Coupling

- change a module
  - version of computation
  - with impact on interface
- change a chair leg
  - specific type of leg
  - impact on leg connection
- change a car part
  - other implementation
  - impact on fixation
- change a study module
  - other content
  - impact on prerequisites
- change an activity module
  - other implementation
  - impact on dependencies
- change a fever ingredient
  - other substance
  - interaction complication
- …

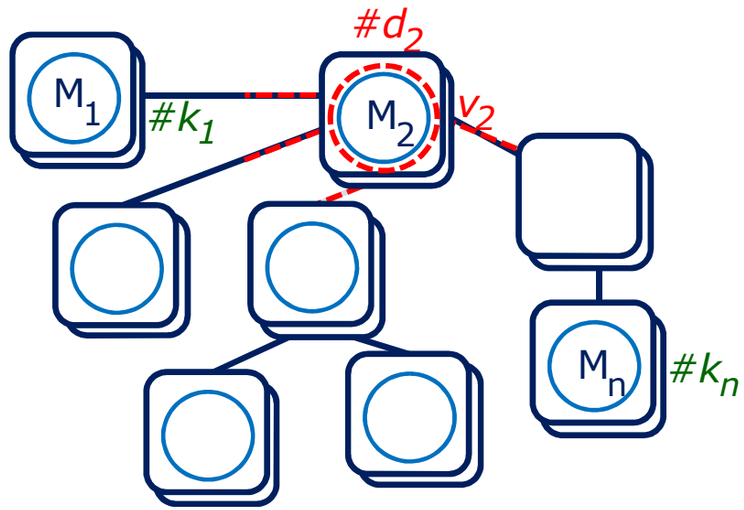


Potential 1st impact: $\sum_{j=0}^{d_i} k_j$

Potential 2nd impact: $\sum_{j=0}^{d_i} \left[\sum_{l=0}^{d_j} k_l \right]$

Coupling has Many Faces

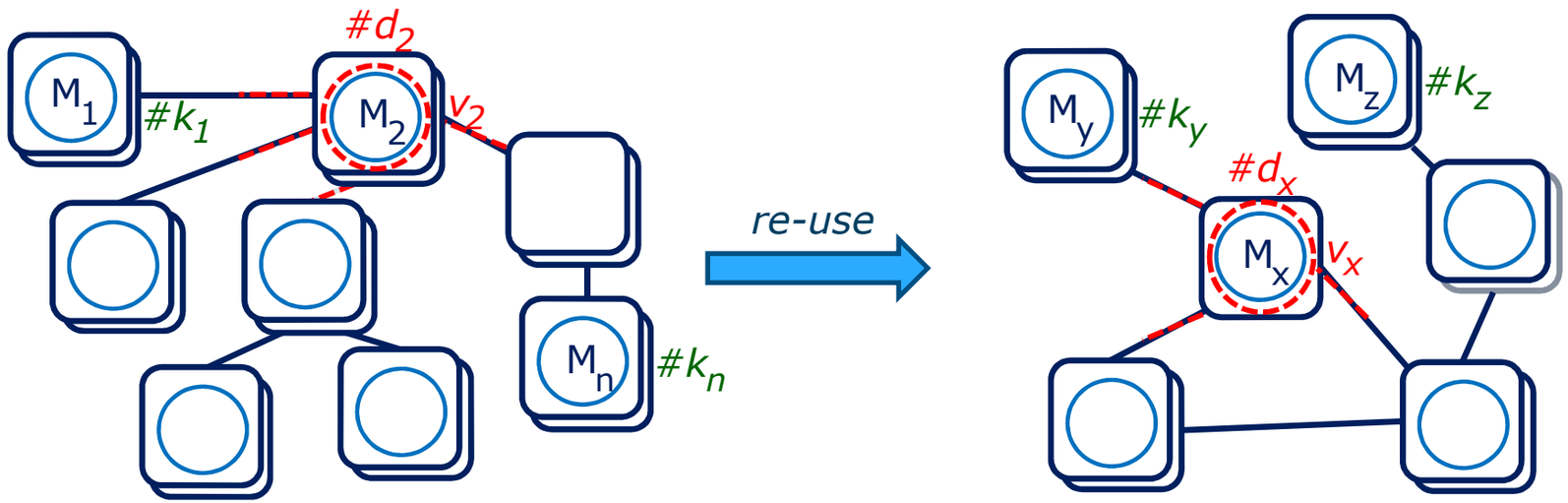
- change a module
  - requires new version jdk
  - answer comes back async
- change a chair leg
  - hardness is damaging
  - must be mounted earlier
- change a car part
  - cooling liquid too viscous
  - should be fixated earlier
- change a study module
  - exam facilities limited
  - requires other module first
- change an activity module
  - other authorization scheme
  - other task prerequisite
- change a fever ingredient
  - impact on solubility
  - needs direct pressurization
- …



Potential 1st impact: $\sum_{j=0}^{d_i} k_j$

Potential 2nd impact: $\sum_{j=0}^{d_i} \left[\sum_{l=0}^{d_j} k_l \right]$

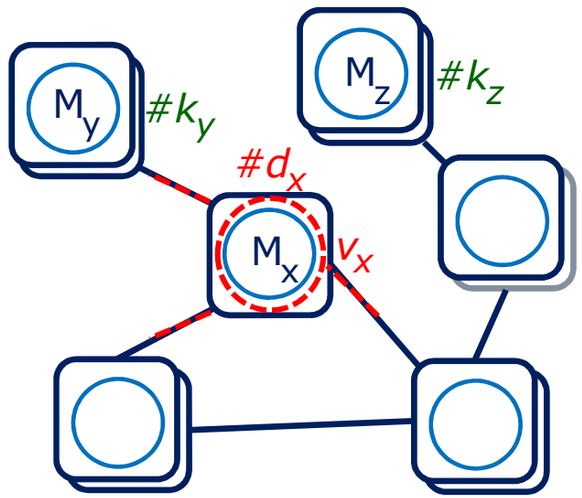
Combinatorics of Re-Use



Change: Exponential Ripple Costs

Combinatorics of Re-Use

- re-use a module
  - in another program
  - changed the interface
- re-use a chair leg
  - in another chair or table
  - changed the leg connection
- re-use a car part
  - In second car or motorbike
  - changed the part fixation
- re-use study modules
  - in another program
  - changed the outcomes
- re-use activity module
  - in other processes
  - changed the dependencies
- re-use fever ingredient
  - in another medicine
  - changed the strength
- …



Modularity Combinatorics

Unleashing the exponential variation gains,
without mastering the coupling
that entails the exponential ripple costs,
may destroy the evolvability.

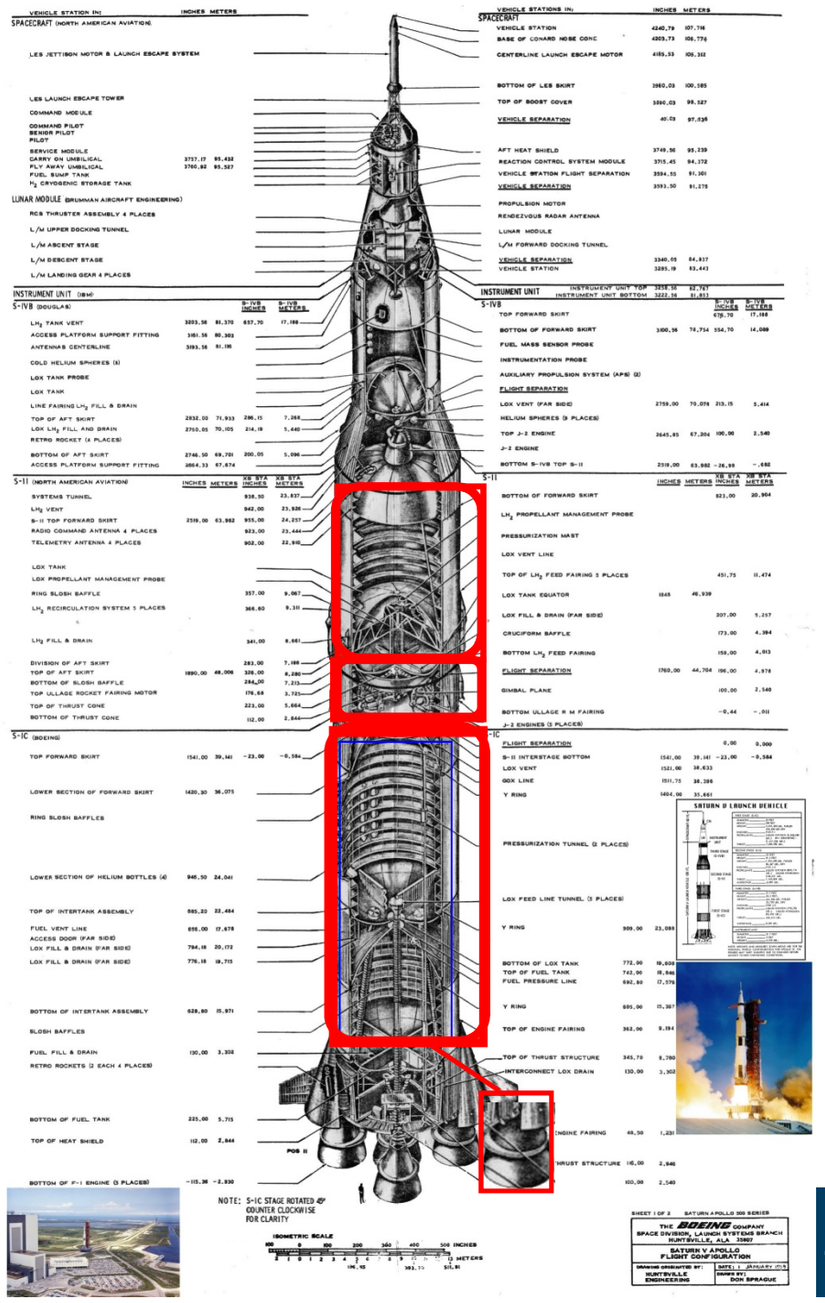
The Reality: Manny Lehman

The Law of Increasing Complexity
Manny Lehman

"As an evolving program is continually changed, its complexity, reflecting deteriorating structure, increases unless work is done to maintain or reduce it."

Proceedings of the IEEE, vol. 68, nr. 9, september 1980, pp. 1068.

Modularity is static



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MULTIPLE DIMENSIONS IN MODULAR STRUCTURES

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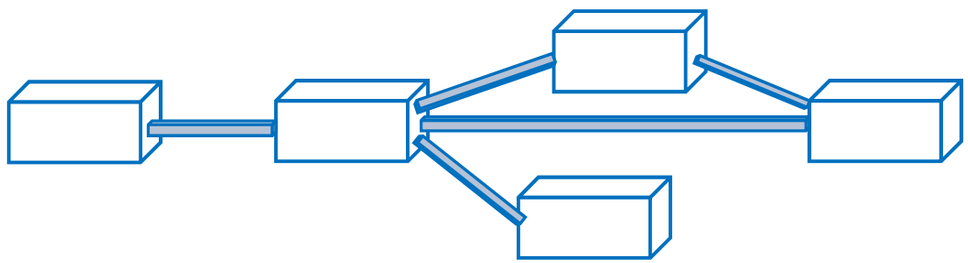
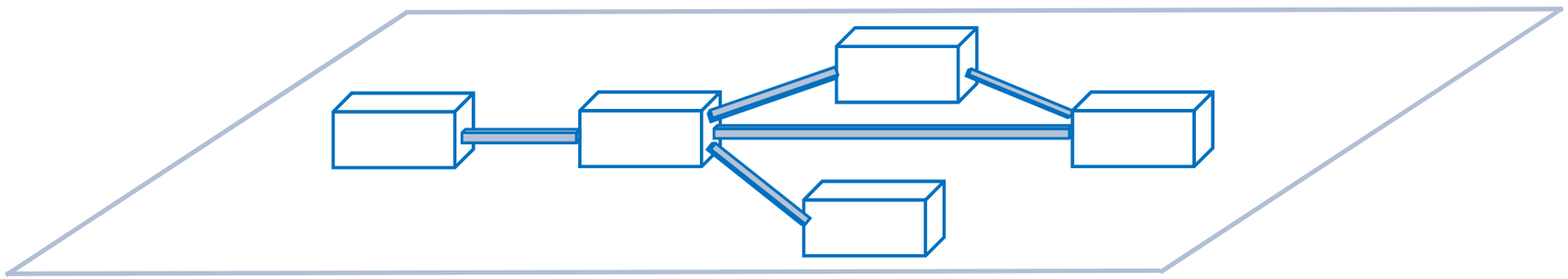
Hierarchical Aggregation



The Integration Problem

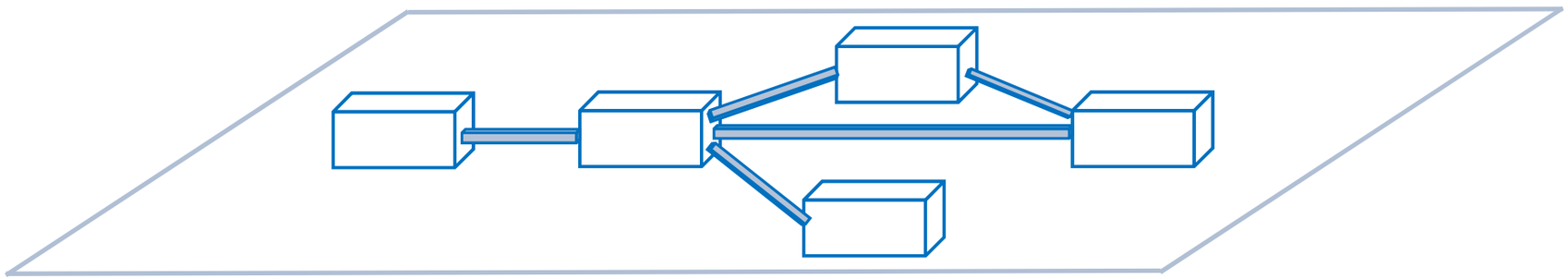
- Making a software application highly robust and secure may imply redevelopment
- Adding water and electricity to a construction plan may imply several rollbacks
- Taking into account weight/vibration/emission constraints may imply redesign of an engine
- …

Hierarchical Aggregation



Introducing Other Concerns

- Adding persistency or access control to all modules containing data
- Adding electrical power and control to the majority of car parts
- Asking internationalization and case studies from course modules
- Demanding secure registration or logging from process activities



Ripple Costs due to Concerns

Potential 1st impact:

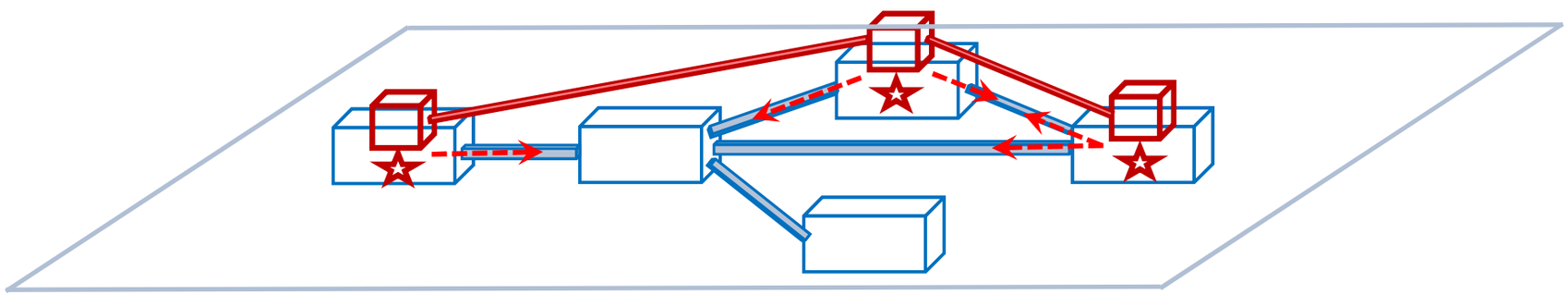
$$\sum_{i=0}^{N} k_i$$

Potential 2nd impact:

$$\sum_{i=0}^{N} \sum_{j=0}^{d_i} k_j$$

Potential 3rd impact:

$$\sum_{i=0}^{N} \sum_{j=0}^{d_i} \sum_{l=0}^{d_j} k_l$$



ARCHITECTURES CONNECTING MODULAR DIMENSIONS

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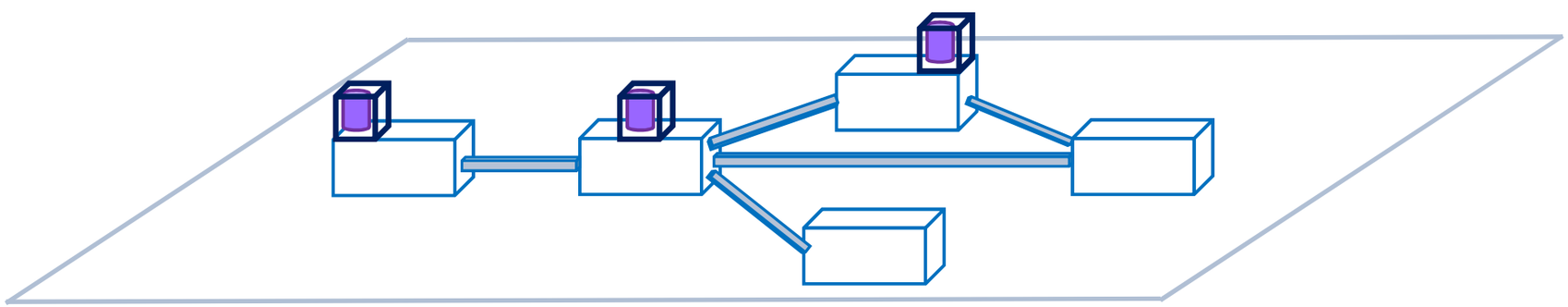
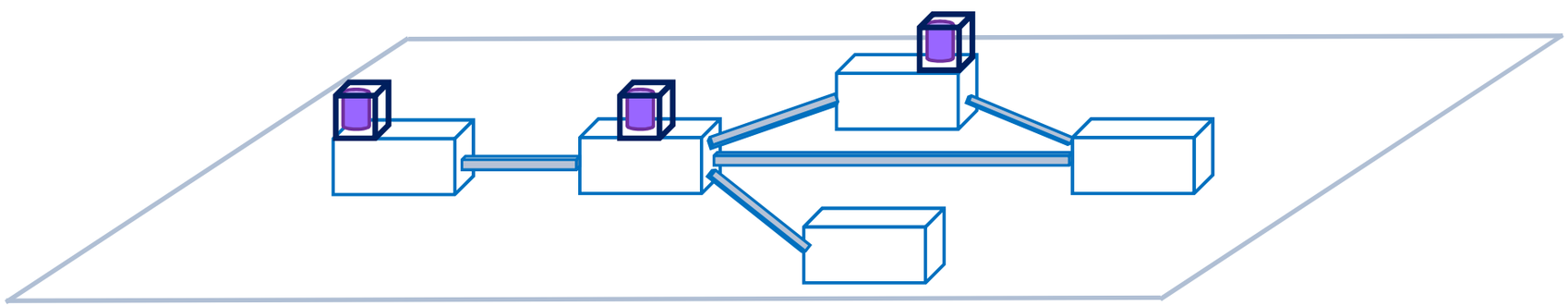
Embedded Dedicated Implementations

- Adding dedicated persistency module to every functional module
- Adding dedicated generator or battery to the majority of car parts
- Develop separate case study module for every course module
- Introduce dedicated secure registration module for every activity



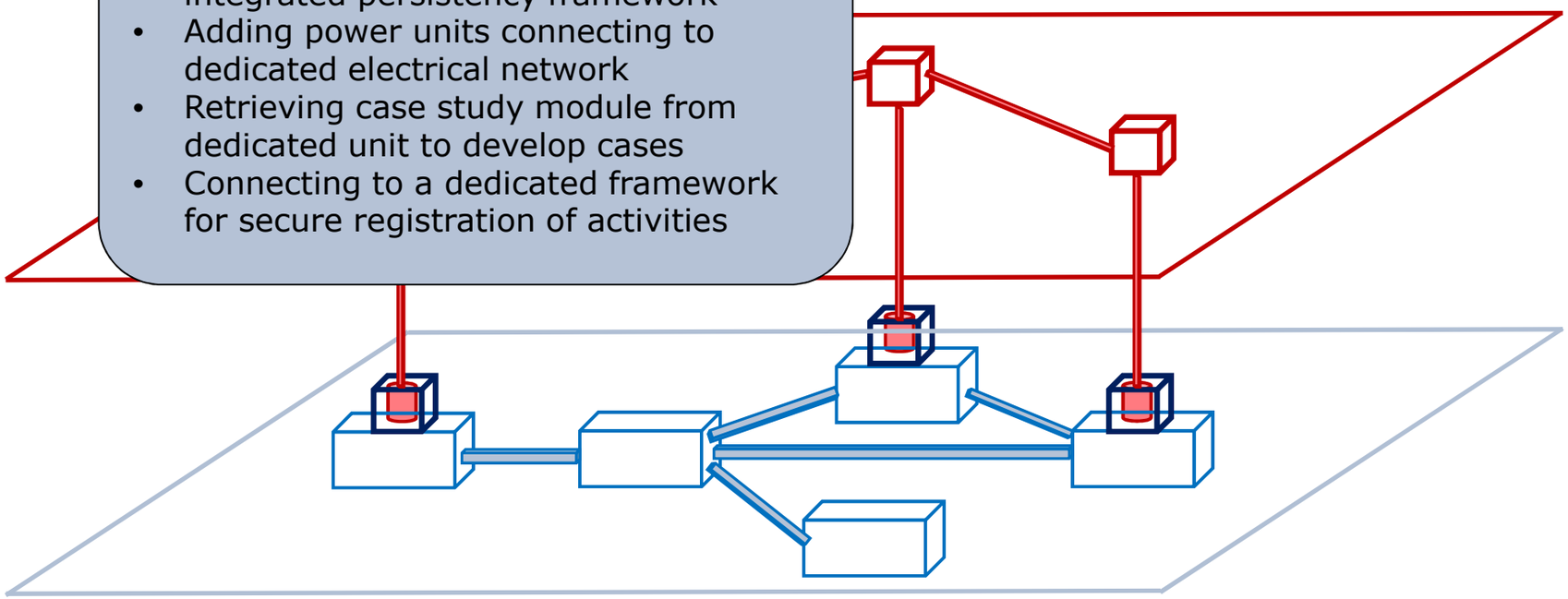
Embedded Standardized Implementations

- Adding standardized persistency module to every functional module
- Adding standardized battery unit to the majority of car parts
- Select standard case study module for every course module
- Introduce standardized secure registration module for every activity

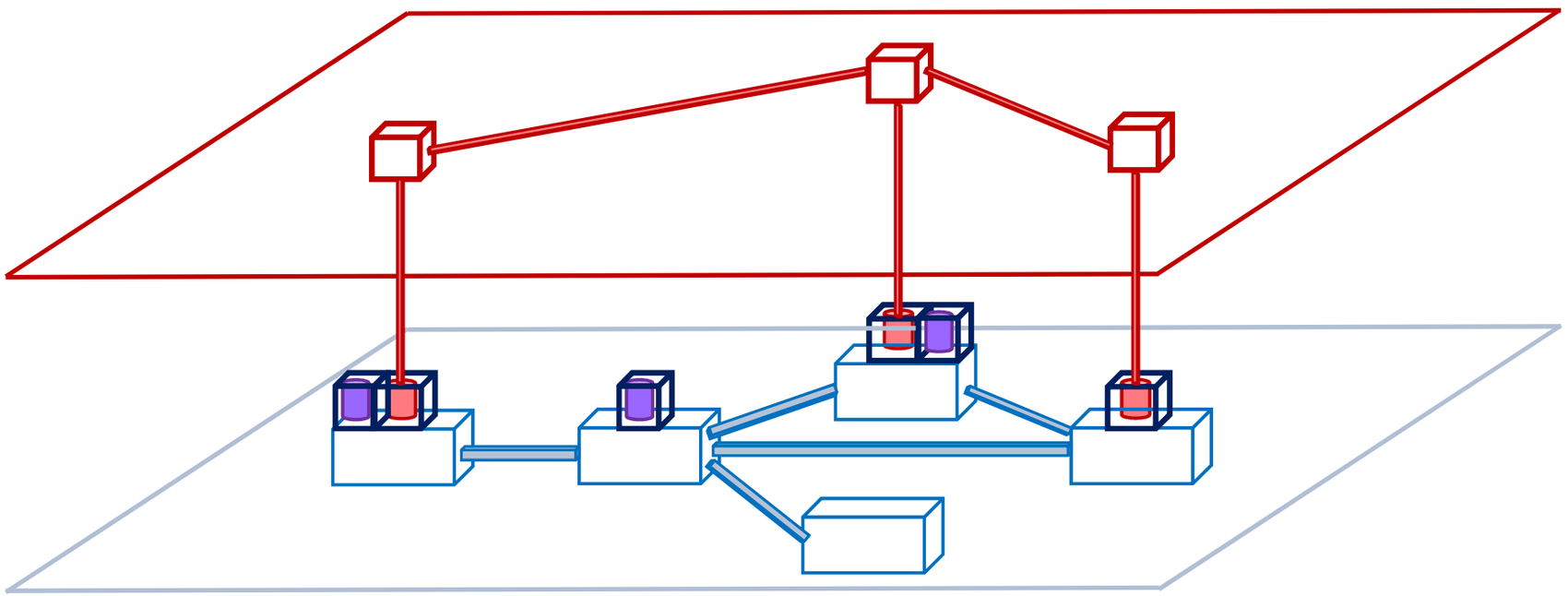


Relay Modules to Dedicated Frameworks

- Adding relay modules to connect to integrated persistency framework
- Adding power units connecting to dedicated electrical network
- Retrieving case study module from dedicated unit to develop cases
- Connecting to a dedicated framework for secure registration of activities

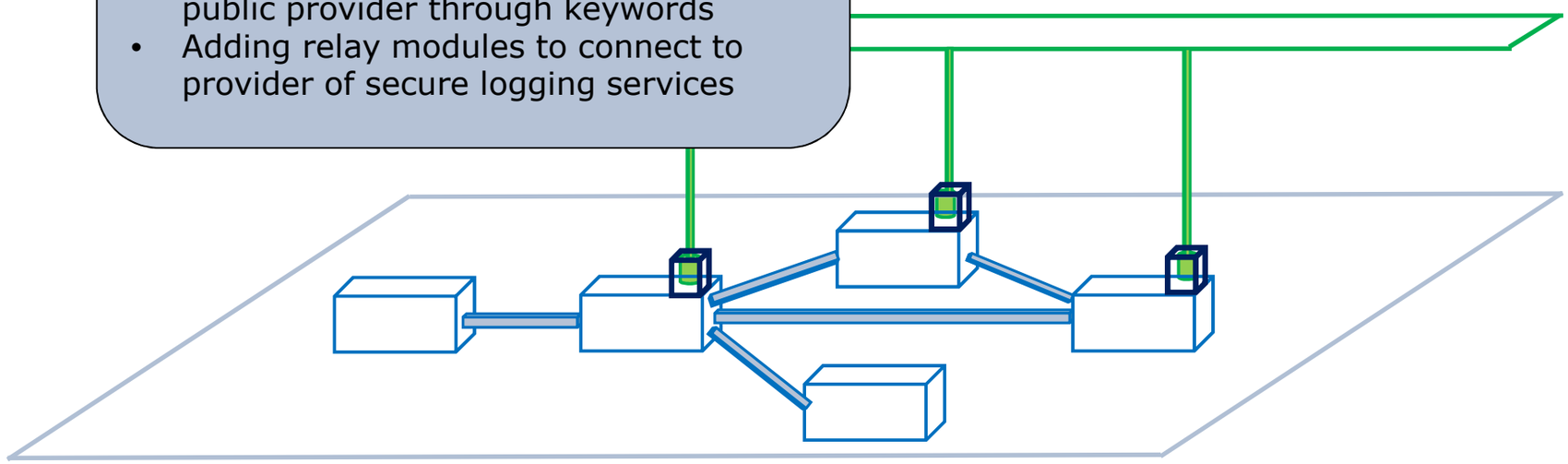


Architectures: 1, 2, and 3



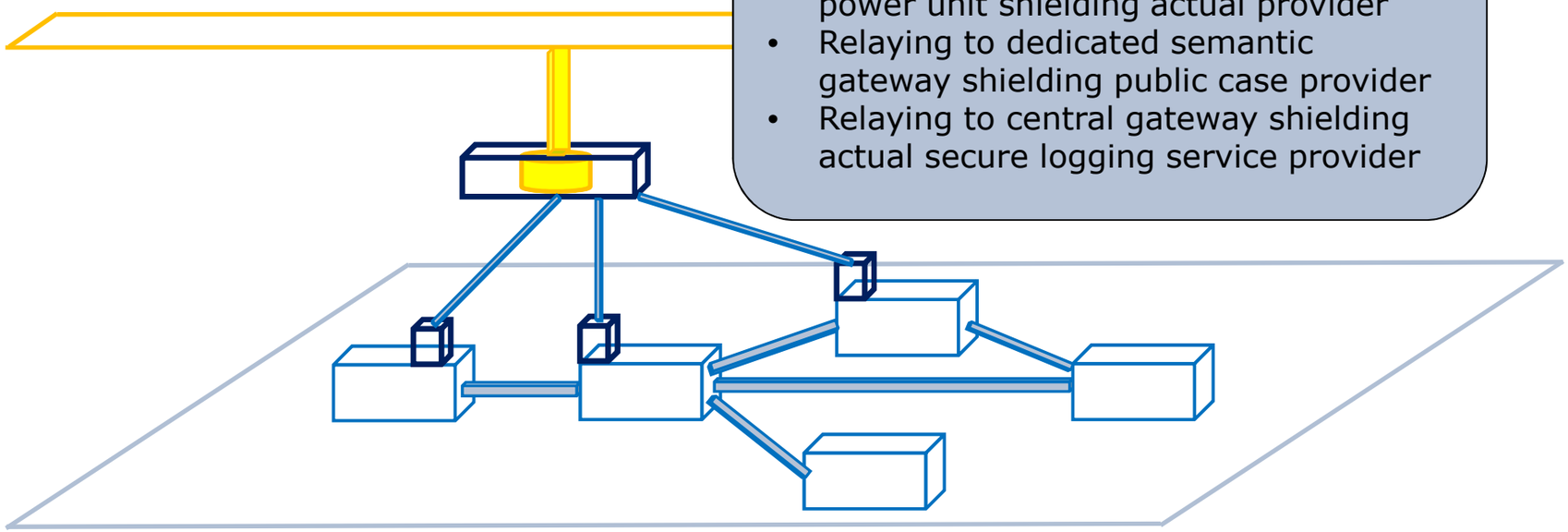
Relay Modules to Standardized Frameworks

- Adding relay modules to tap into immanent standard solution like JPA
- Adding standard connectors to tap into standardized electrical network
- Retrieving case study modules from public provider through keywords
- Adding relay modules to connect to provider of secure logging services

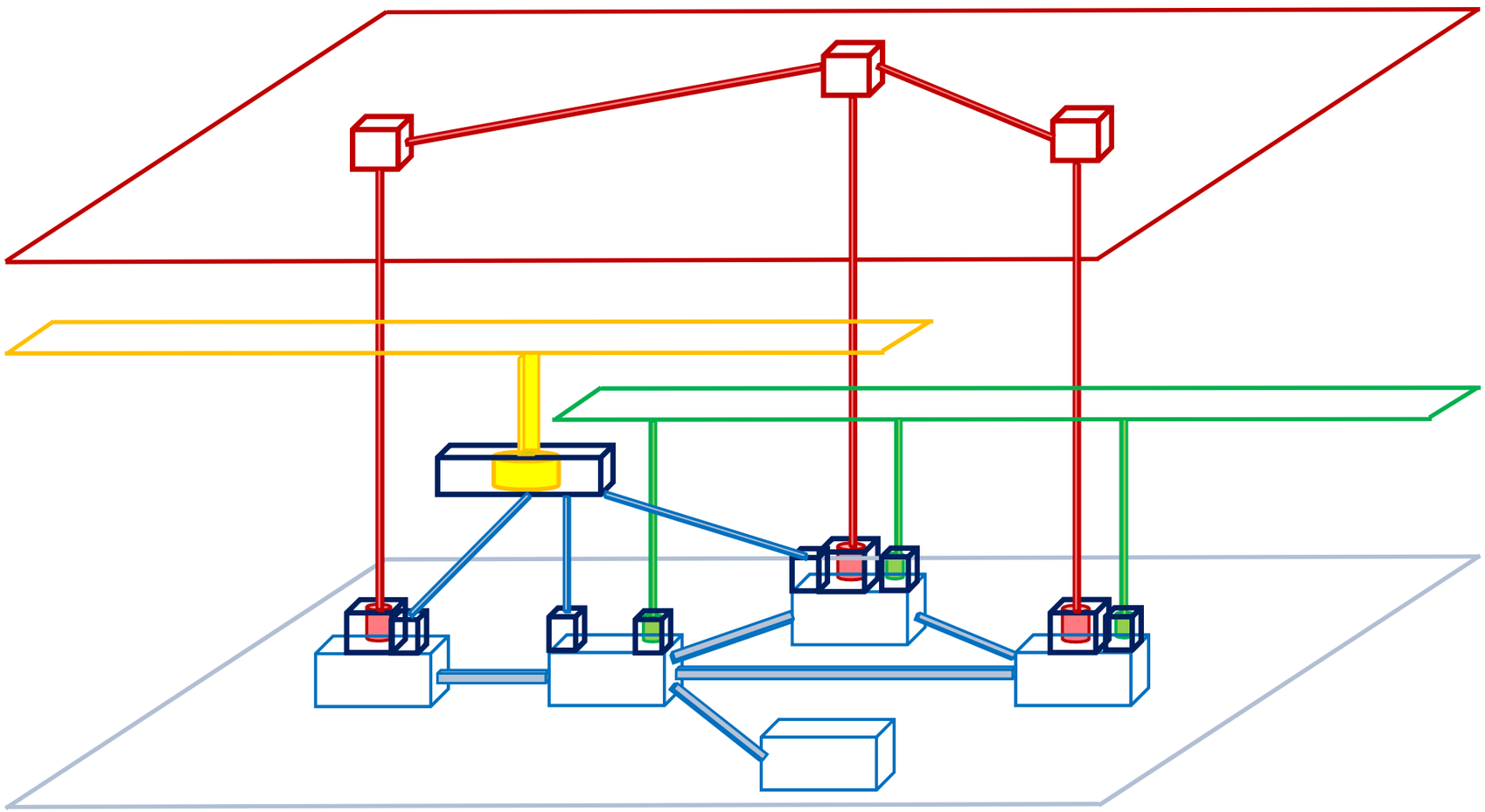


Relay Modules to Framework Gateways

- Relaying persistency authorization to dedicated gateway shielding provider
- Power connectors relaying to central power unit shielding actual provider
- Relaying to dedicated semantic gateway shielding public case provider
- Relaying to central gateway shielding actual secure logging service provider



Architectures: 3, 4, and 5



Aggregating Concerns: Case

INTEGRATED ELEMENTS THAT EXHIBIT EVOLVABILITY

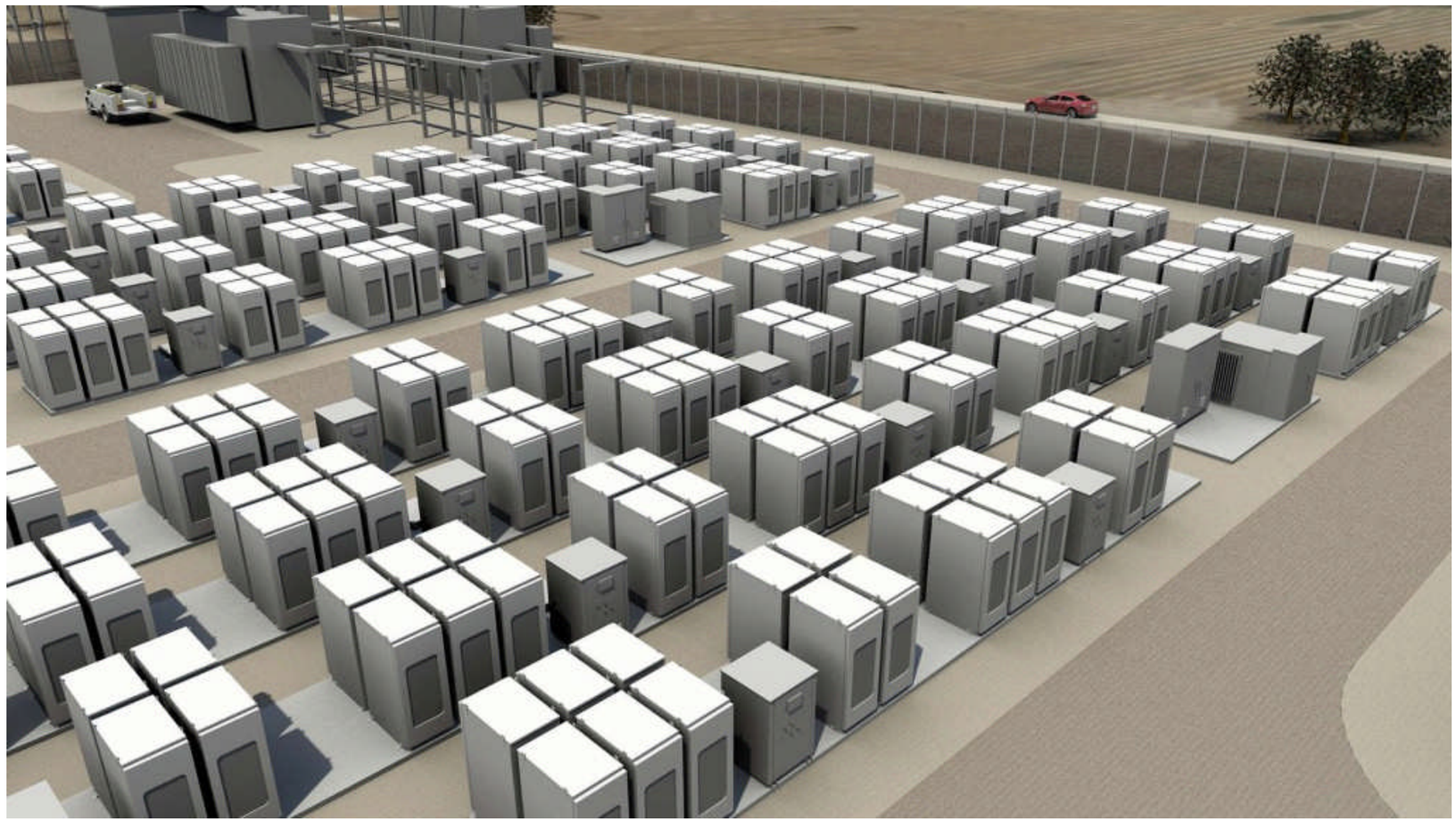
Universiteit Antwerpen

Some Attempts Towards Evolvability and Scalability

Some Attempts Towards Evolvability and Scalability

Google
Modular
Phones

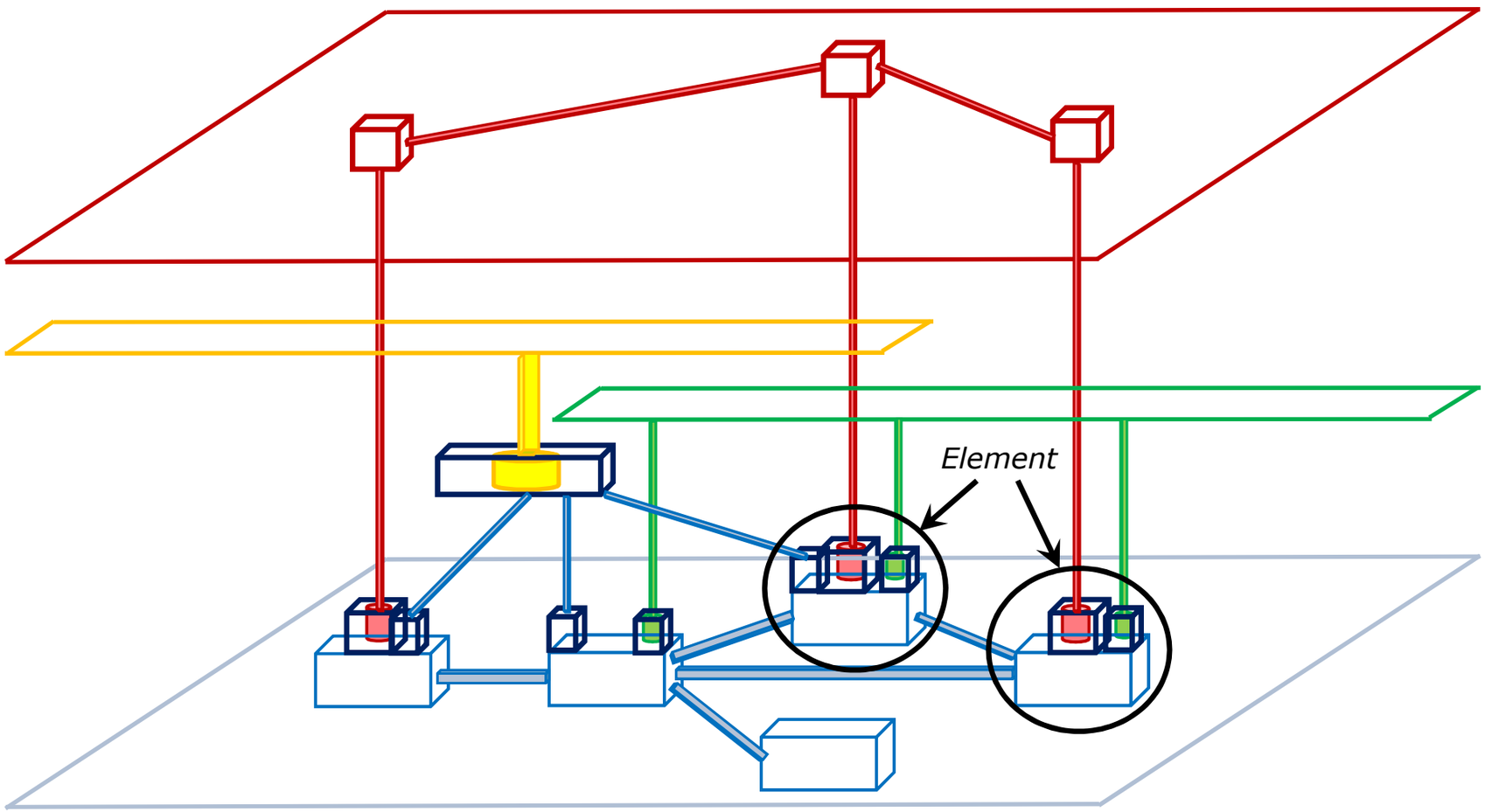
Some Attempts Towards Evolvability and Scalability



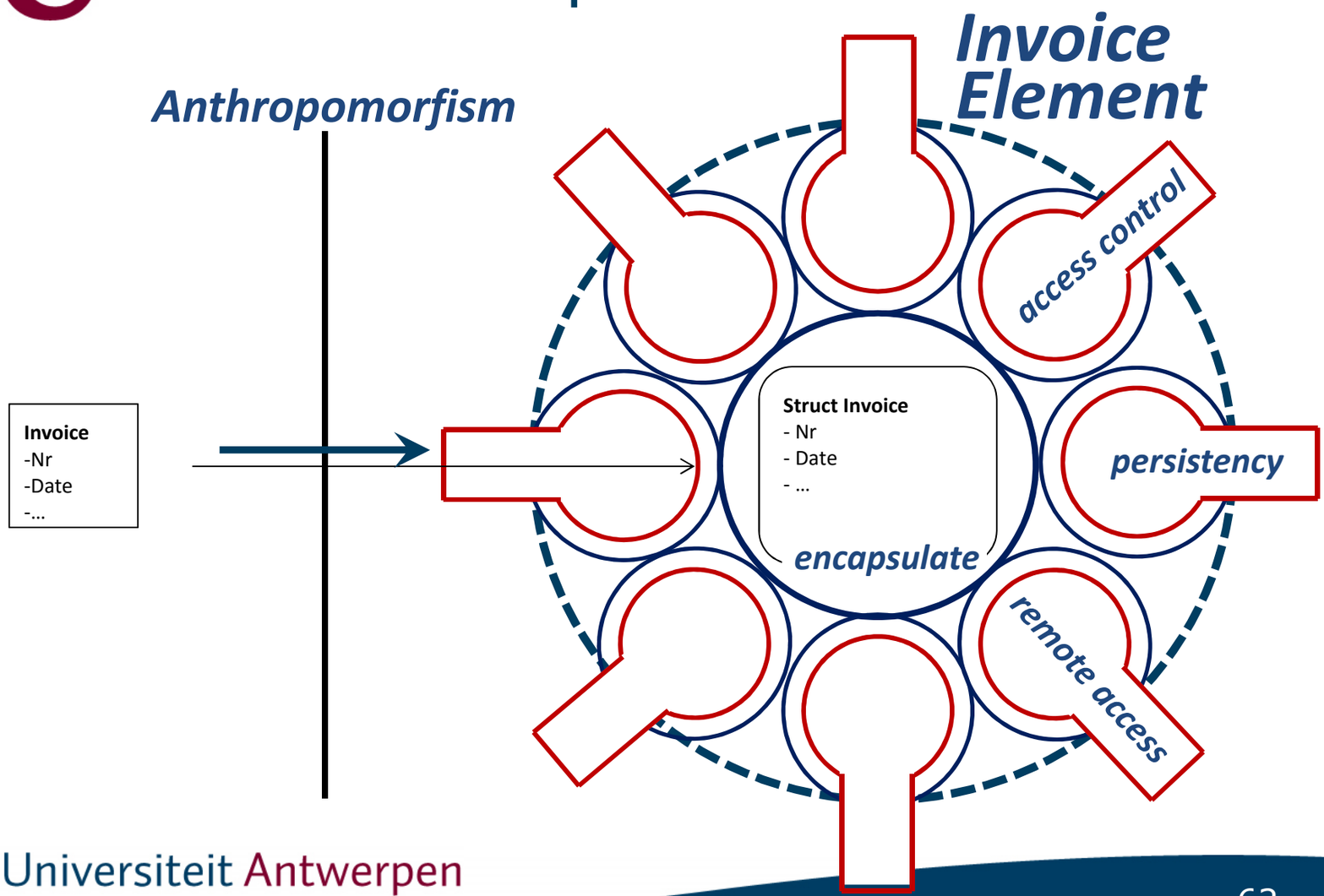
The Emergence of Elements

- Additional concerns should be systematically distributed throughout the functional structure
- The integration of such a concern should be done in a properly encapsulated/isolated way
- For every concern, an architecture needs to be designed, as standardized as possible
- The integration skeletons need to be provided as deep down as possible in modular structure

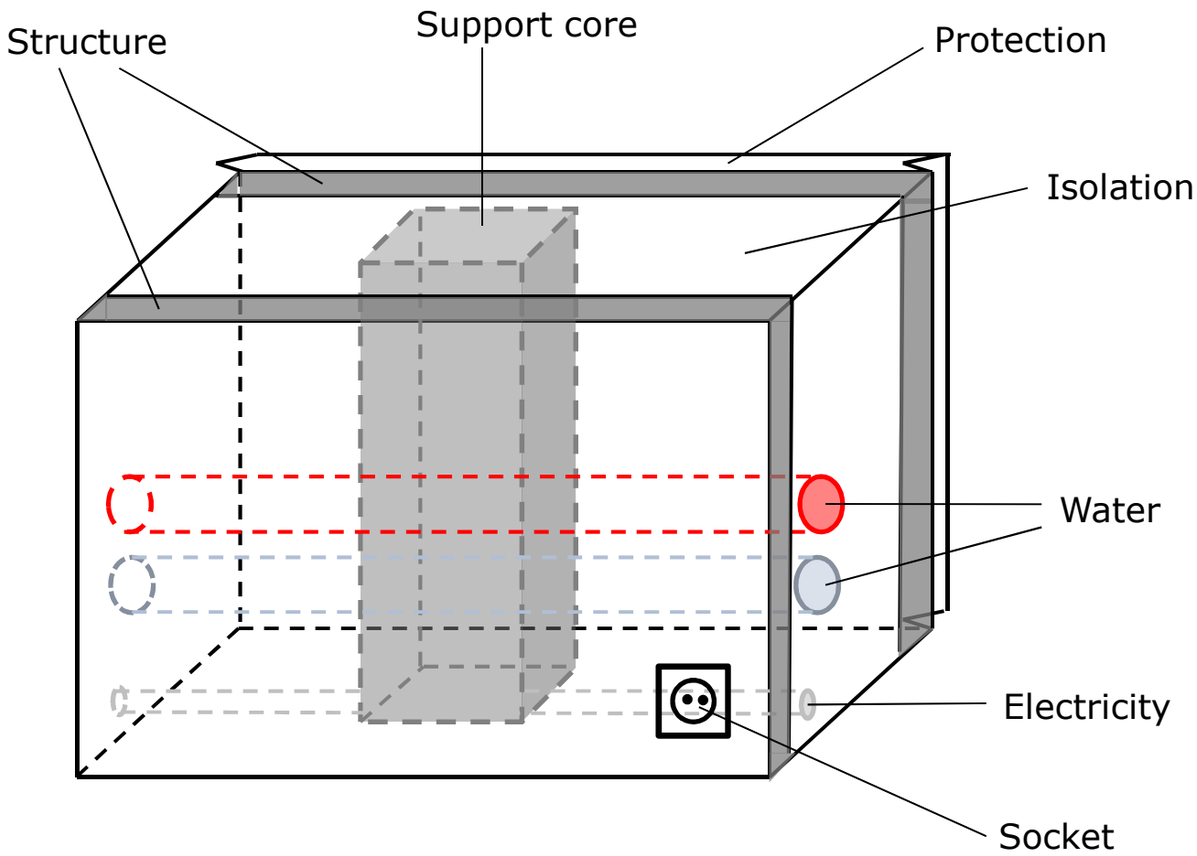
The Emergence of Elements



Concept Element: Software

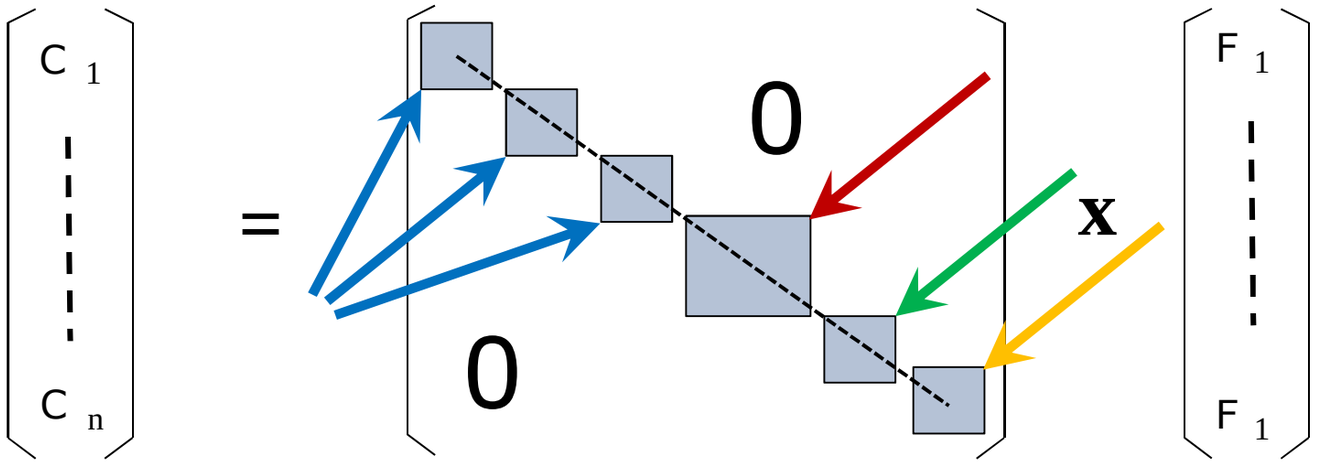


Concept Element: Construction



Normalized Systems Elements

- The ultimate goal is to *normalize systems*:
  →to have a normalized transformation:
  between function and construction



→based on elementary building blocks:
that solve the m:n design problem

Imagine …

- Houses that could be reconfigured or extended without additional plumbing or electricity works …
- Roads and footpaths that could be moved entirely without additional drilling for sewer or cable networks …
- Software systems that could be maintained and evolved without increasing costs and ripple effects …
- Cars, airplanes, and rockets that could be scaled up and down to carry more or less passengers or freight …
- …

Imagine …

The sciences of the evolving and growing artificial

Table of Contents

Conclusions

- We should study more modularity in general, and characteristics of modular patterns
- There is a tendency to introduce modules for flexibility, and to reap the variation gains
- Unleashing variation gains without mastering coupling, may be very harmful to evolvability
- We should address the multi-dimensional nature of architectural design problems
- The concept of multi-concern elements may contribute to growing and evolving artefacts

Questions