Correct by construction software development

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Outline

- Introduction

- System Design
- Correct by Construction
- Discussion

The Evolution of Computer Science

- Convergence between Computing and Telecommunications
- Graphic Interfaces, Mouse

Scientific Computing – Defence Applications

Multi-core Systems

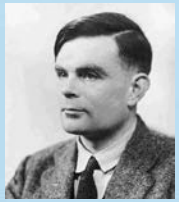
WEB – Information Society

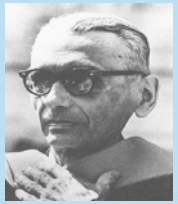
1945 1980 1990 2010

1936 1970 2000 2015

Foundations - Alan Turing, Kurt Gödel

Embedded Systems: Computing + Physicality
- Seamless revolution
- 95% of chips are embedded





- Information Systems: Commercial Applications
- Integrated circuits

The Internet of Things: Convergence between Embedded Systems and the Web

Systems vs Programs – The Hardest and the Most Important

Significant differences

Programs
- terminating
- deterministic
- platform-independent
- Theory

System
- non-terminating
- non-predictable
- platform-dependent
- No theory!

Systems

- are hard to design due to unpredictable and subtle interactions with the environment, emergent behaviors, and occasional catastrophic cascading failures rather than to complex data and algorithms

- are increasingly important in modern computing systems: embedded systems, cyber-physical systems, mobile systems, web-services

What is needed?

We need new methods for designing and verifying systems in which physical characteristics are determined (or influenced) computationally and the other way around.

System Design – About Design

Design is a universal concept,
a par excellence intellectual activity
leading to artifacts meeting given requirements.

Easy Apple Pie

Proceduralization

RECIPE
(Program)

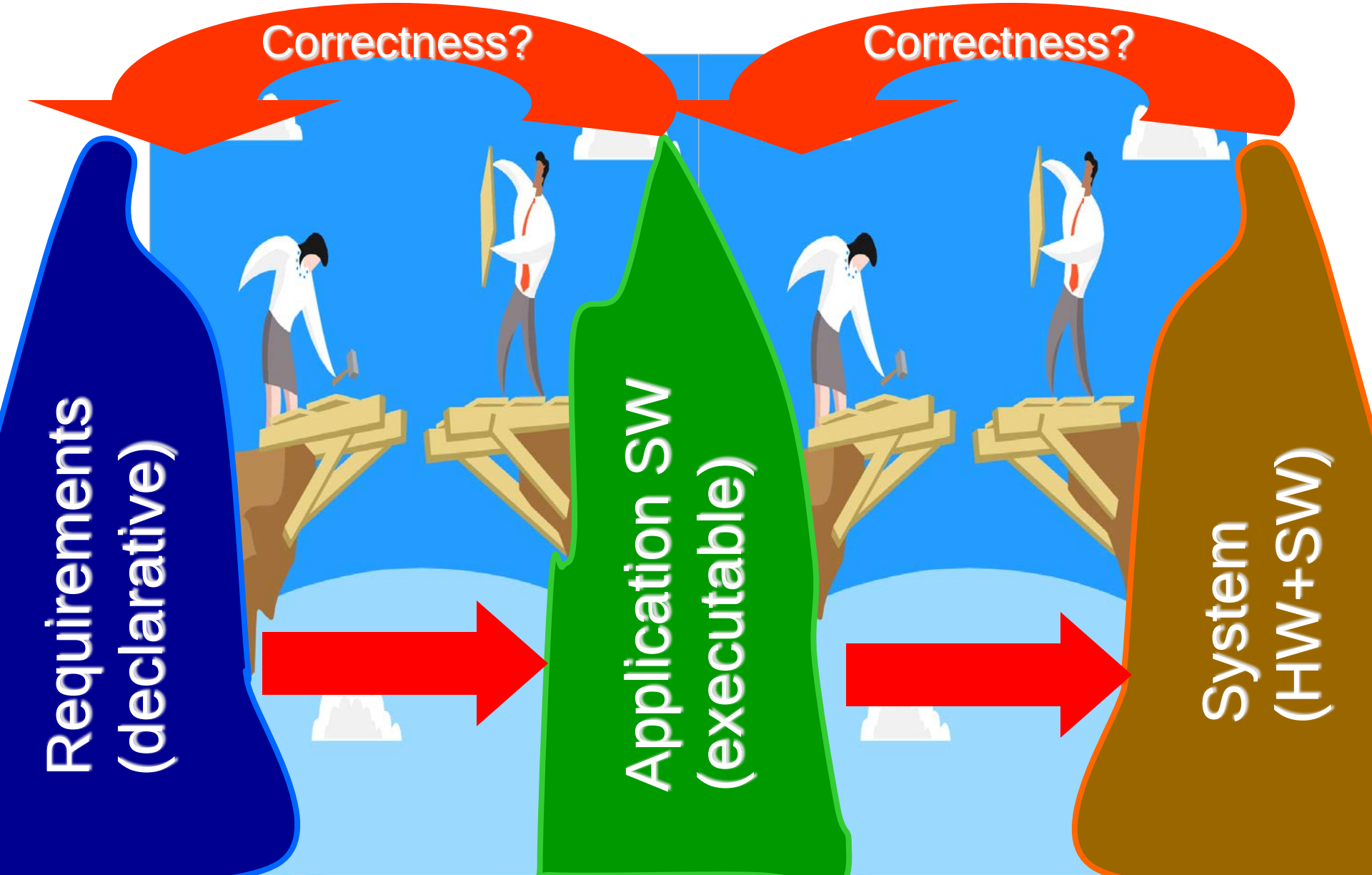
- Put apples in pie plate;
- Sprinkle with cinnamon and 1 tablespoon sugar;
- In a bowl mix 1 cup sugar, flour and butter;
- Blend in unbeaten egg, pinch of salt and the nuts;
- Mix well and pour over apples;
- Bake at 350 degrees for 45 minutes

Materialization

INGREDIENTS
(Resources)

- 1 pie plate buttered
- 5or 6 apples, cut up
- ¾ c. butter, melted
- 1 c. flour
- ½ c. chopped nuts
- 1tsp cinnamon
- 1tbsp sugar
- 1c. Sugar

System Design – Two Main Gaps



System Design – Correctness: Reminder

Trustworthiness requirements express assurance that the designed system can be trusted that it will perform as expected despite

HW failures

Design Errors

Environment Disturbances

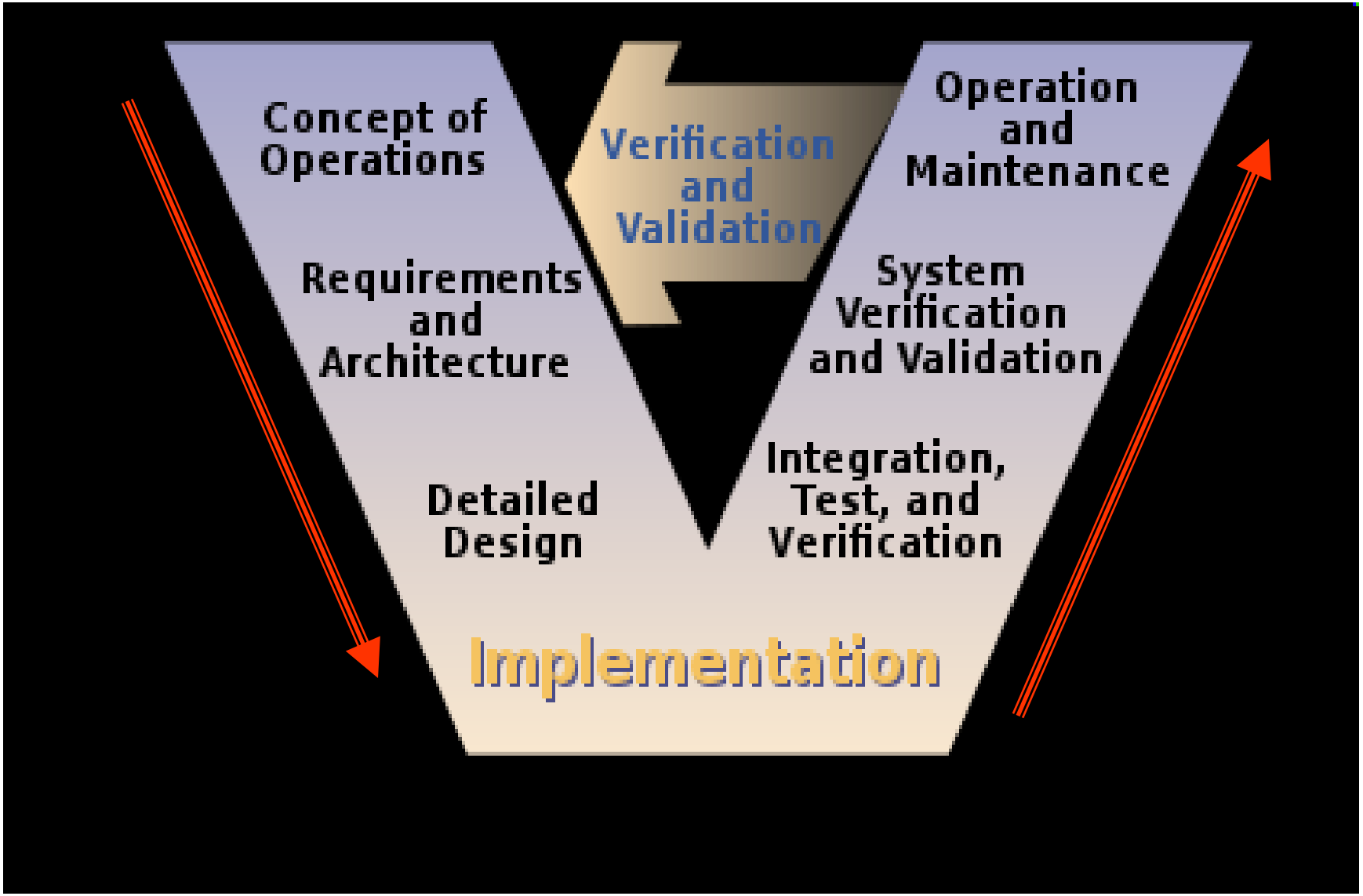
Malevolent Actions

Optimization requirements dealing with optimization of functions subject to quantitative constraints on

1) Performance: how well the system does wrt user demands e.g. throughput, jitter, latency, quality.
2) Cost: how well resources are used wrt economic demands e.g. storage efficiency, processor utilizability, energy efficiency.

Usually they determine tradeoffs between performance and cost

System Design – The V-model



The V-model of the Systems Engineering Process, Source: Wikipedia

System Design – The V-model

The V-model of the traditional Systems Engineering process

1. assumes that all the system requirements are initially known, can be clearly formulated and understood.

2. assumes that system development is top-down from a set of requirements. Nonetheless, systems are never designed from scratch; they are built by incrementally modifying existing systems and component reuse.

3. considers that global system requirements can be broken down into requirements satisfied by system components. Furthermore, it implicitly assumes a compositionality principle: if components are proven correct with respect to their individual requirements, then correctness of the whole system can be inferred from correctness of its components.

4. relies mainly on correctness-by-checking (verification or testing)

The Limits of Correctness-by-checking (1)

- *Correctness*: **designed artifact meets its requirements specifications**.
- *Ideal for many designers*: **correctness by checking**.
- *Usually impossible*: ***verification method explodes exponentially with the number of components in the artifact***.
- The best we can do is ***limit automatic verification to small*** or ***medium size*** models and to specific properties.

The Limits of Correctness-by-checking: Conclusion

- **correctness-by-checking** of trustworthiness: limited to requirements that can be formalized and checked efficiently.

- **Application to optimization *requirements*: *limited to the validation of scheduling and resource management policies*** on abstract system models (*medium size systems*).

- **For optimization**: a more natural approach for their ***satisfaction*** is ***by enforcing*** rather than by checking.

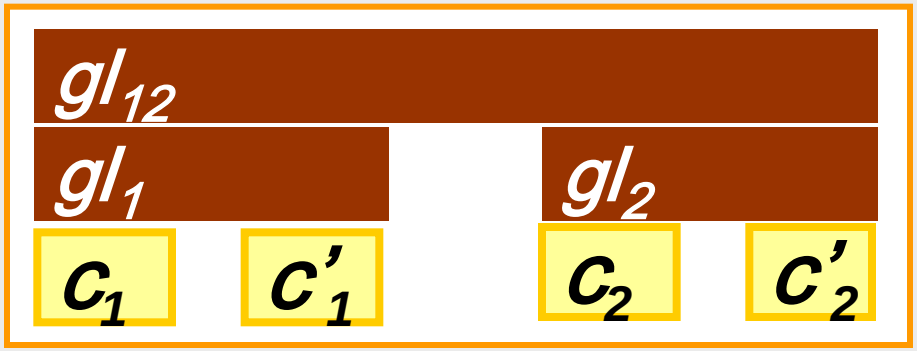
Correct-by-Construction Approaches

- At the root of any mature engineering discipline.
  - scalable and do not suffer limitations of correctness-by-checking.
  - Testing may be still necessary, but its role is to validate the correct-by-construction process rather than to find bugs.
- Methodology to ensure correctness-by construction gradually by acting in two different directions:
  - ***Horizontal correctness***, within a design step, by providing rules for enforcing global properties of composite components while preserving essential properties of atomic components;
  - ***Vertical Correctness***, between design steps to guarantee that if some property is established at some step then it will be preserved at all subsequent steps.

Horizontal Correctness: Property Enforcement

Build a component *C* satisfying a given property *P,* from

- C_0 a set of atomic components modeling behavior
- $GL = \{gl_1, \ldots, gl_i, \ldots\}$ a set of glue operators on components



sat P

Glue operators

- model mechanisms used for communication and control such as protocols, controllers, buses.
- restrict the behavior of their arguments, that is

$$gl(C_1, C_2, \ldots, C_n) | A_1 \text{ refines } C_1$$

Rule1: Property Enforcement

Architecture
for Mutual Exclusion

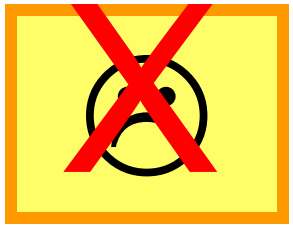
Components

Architecture
for Mutual Exclusion

satisfies Mutex

Horizontal Correctness: Property Composability

Make the new without breaking the old: Rules guaranteeing non interference of solutions



sat P

and

sat P'

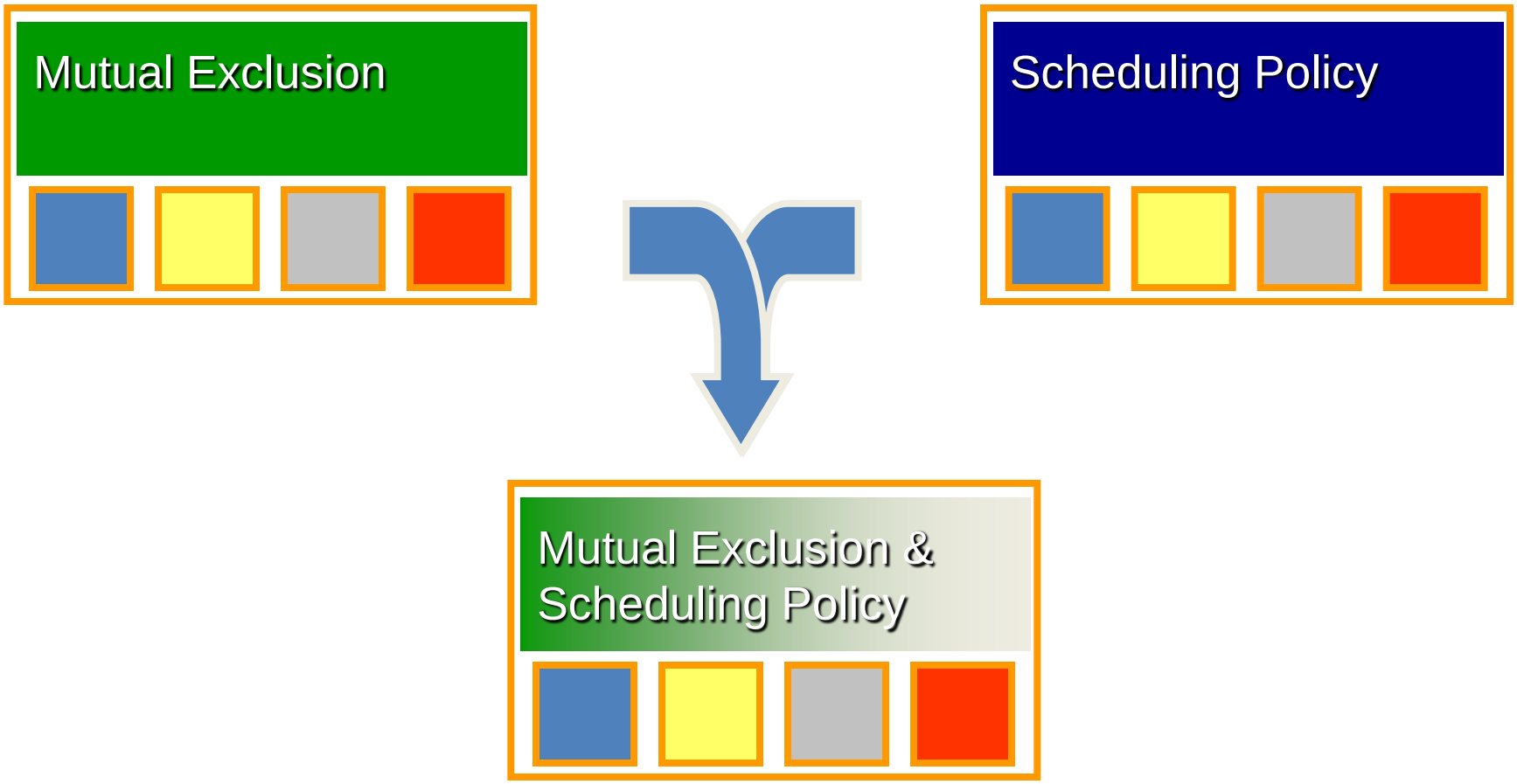
implies

sat P∧P'

Property stability phenomena are poorly understood.
We need composability results e.g. feature interaction in middleware, composability of scheduling algorithms, theory for reconfigurable systems

Horizontal Correctness: Composability

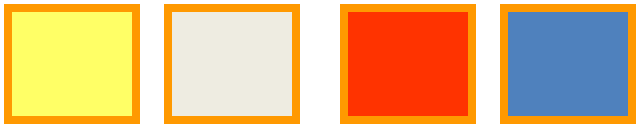
Rule2: Property Composability



Feature interaction in telecommunication systems, interference among web services and interference in aspect programming are all manifestations of a lack of composability

Rule1: Property Preservation

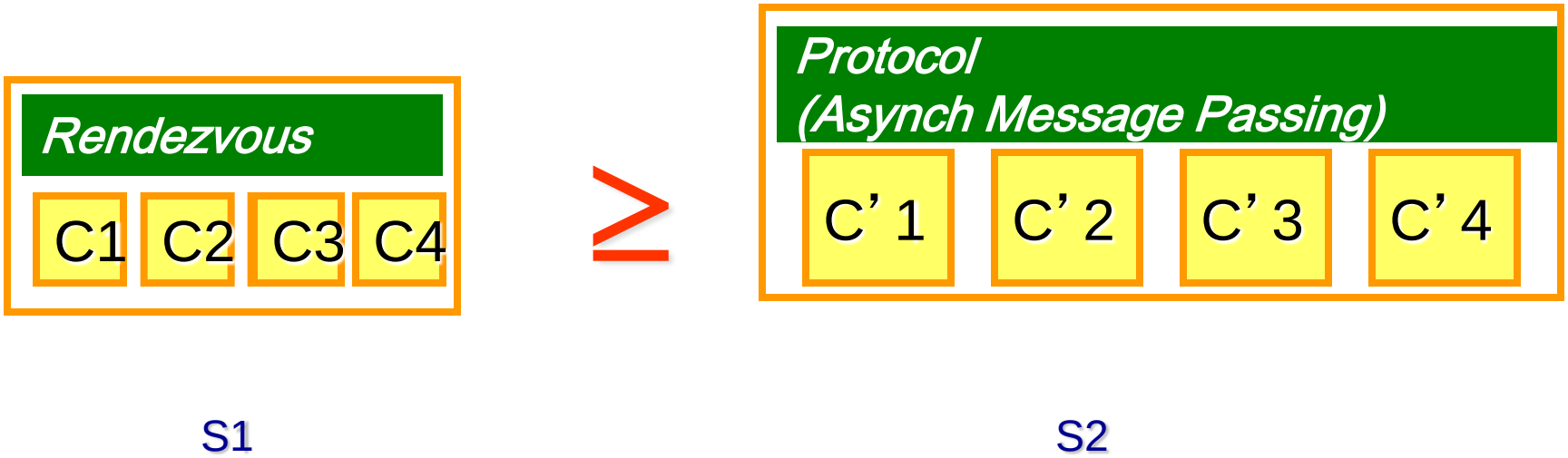
Deadlock-free
Routing Protocol



Deadlock-free components

Deadlock-free
composite
component

The Refinement Relation ≥

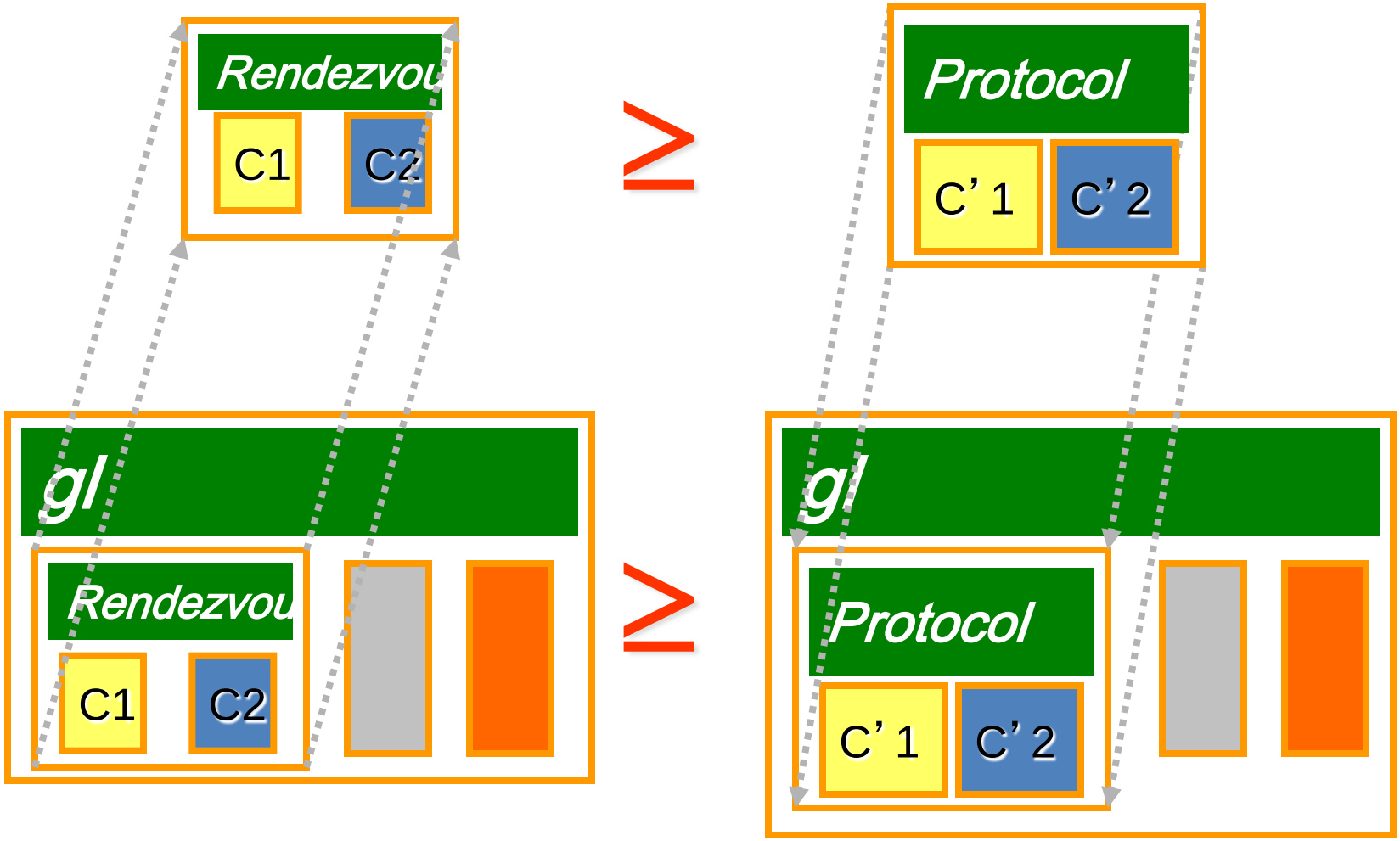


S1 ≥ S2 (S2 refines S1) if

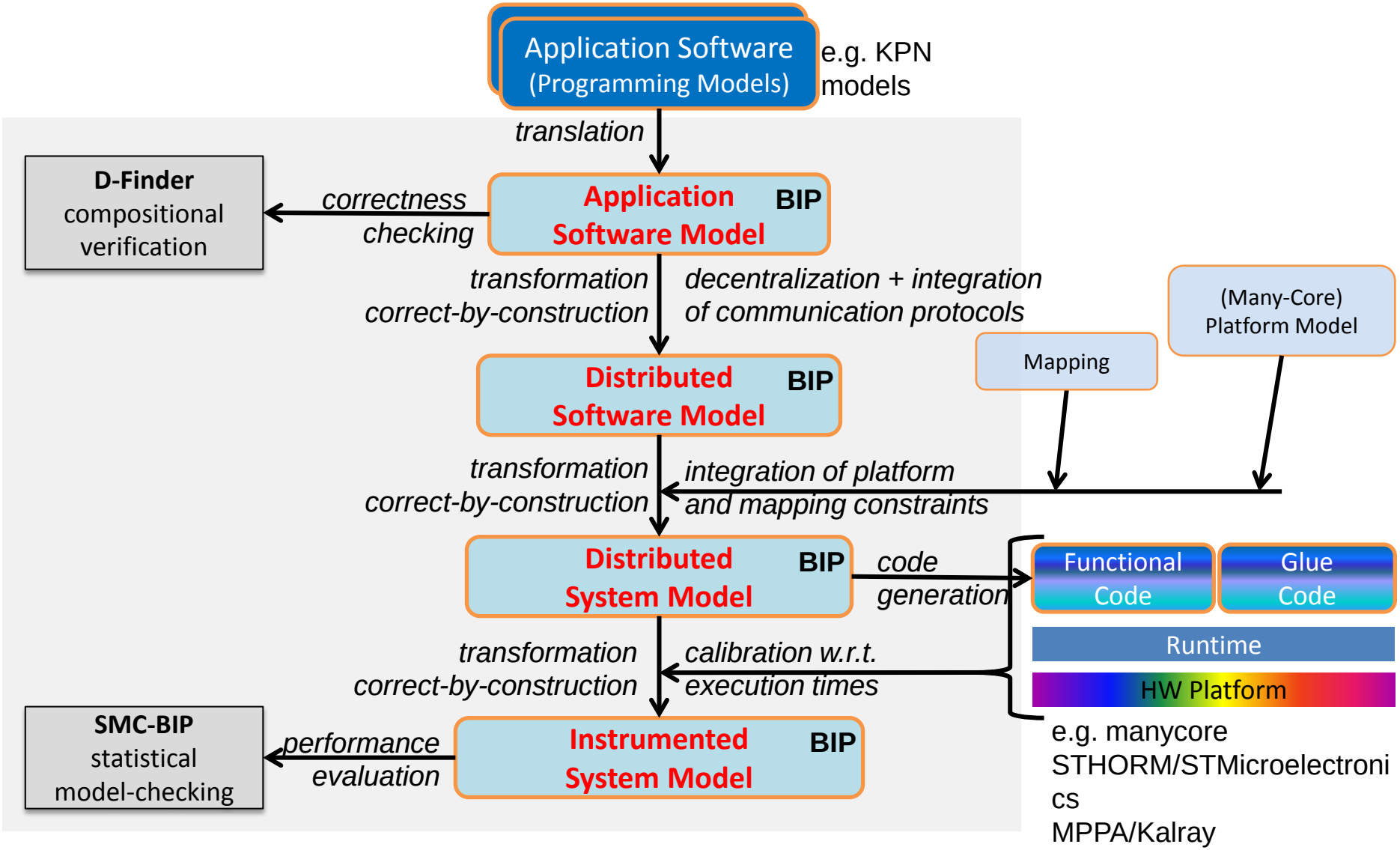
- all traces of S2 are traces of S1(modulo some observation criterion)
- if S1 is deadlock-free then S2 is deadlock-free too
- ≥ is preserved by

Question: Propose adequate refinement relations

Vertical Correctness: Preservation of ≥ substitution



Putting Correctness-by-Construction into Practice: The BIP Design Flow



GenoM - BIP Toolchain

GenoM Models

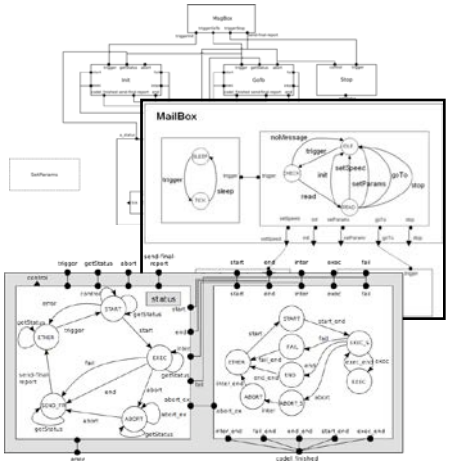
```
module Motion {
  number:  9600;
  SDI:     MOTION_DATA;
}
request SetPos {
  type:     control;
  input:    pos::pos;
  control:  controlPos;
  report:   BAD_PARAM;
}
task Move {
  period:   25;
  priority: 15;
}
```

+

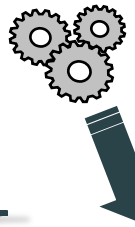
Codels

+

BIP Models

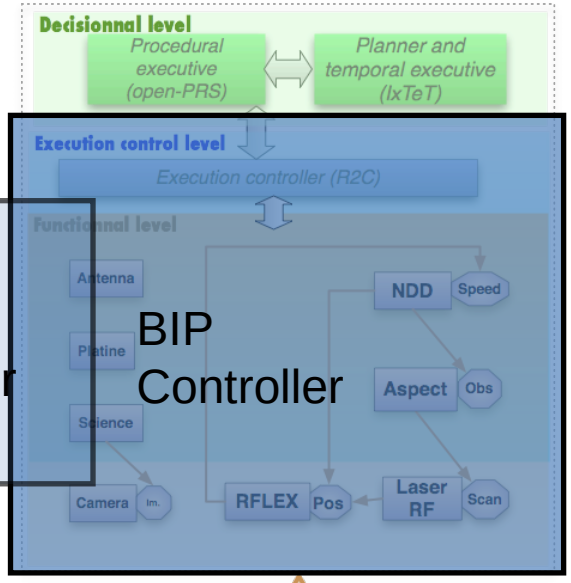


BIP



BIP Controller

BIP Controller



BIP Controller

OR

Module X Functional Module

Pos Y Poster

D-Finder

- Thanks for your attention.

Questions?