Generating Distributed Implementations for BIP

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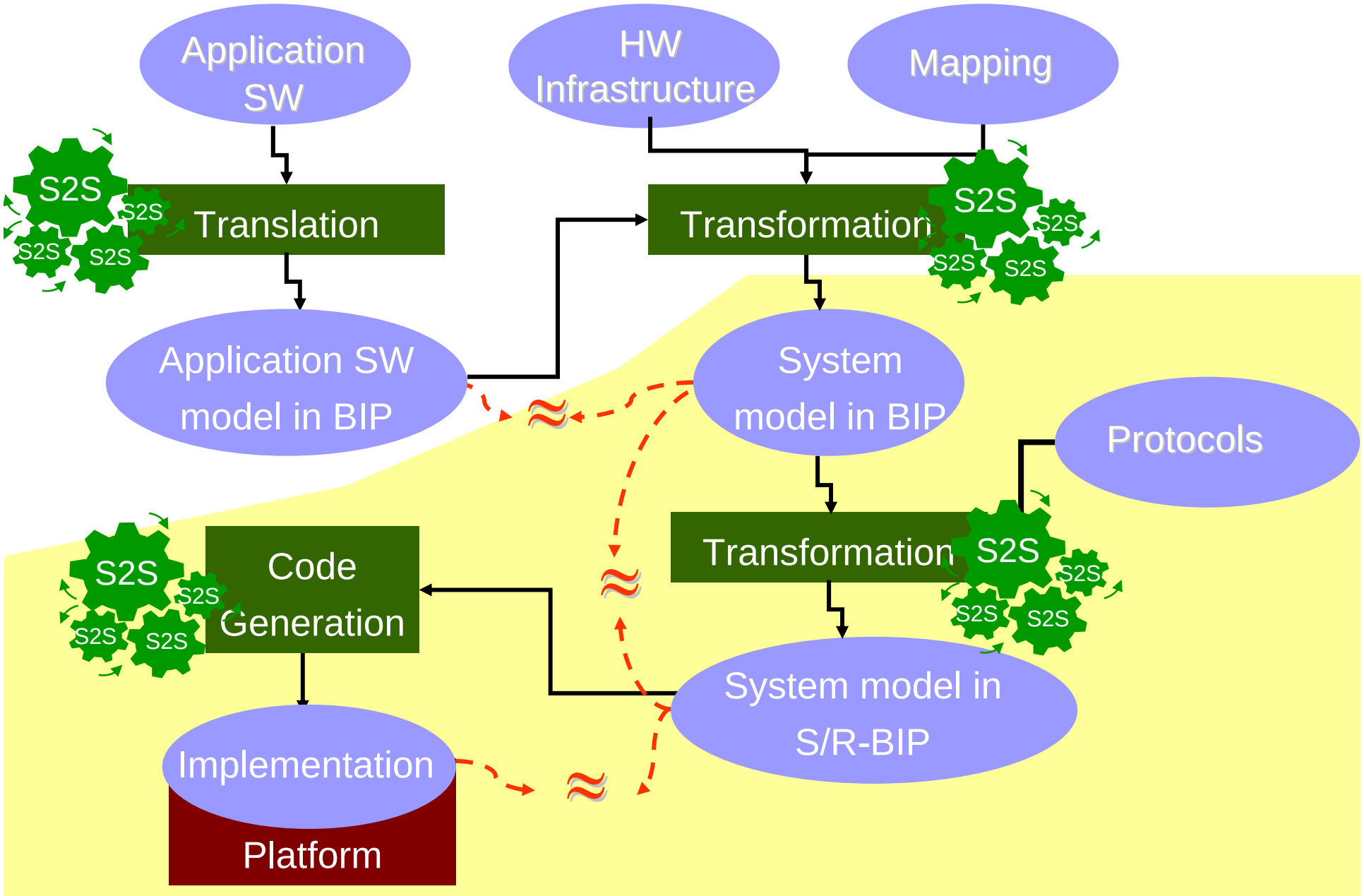
Rigorous System Design

A rigorous system design flow allows guaranteeing that the designed system meets some essential requirements. It is

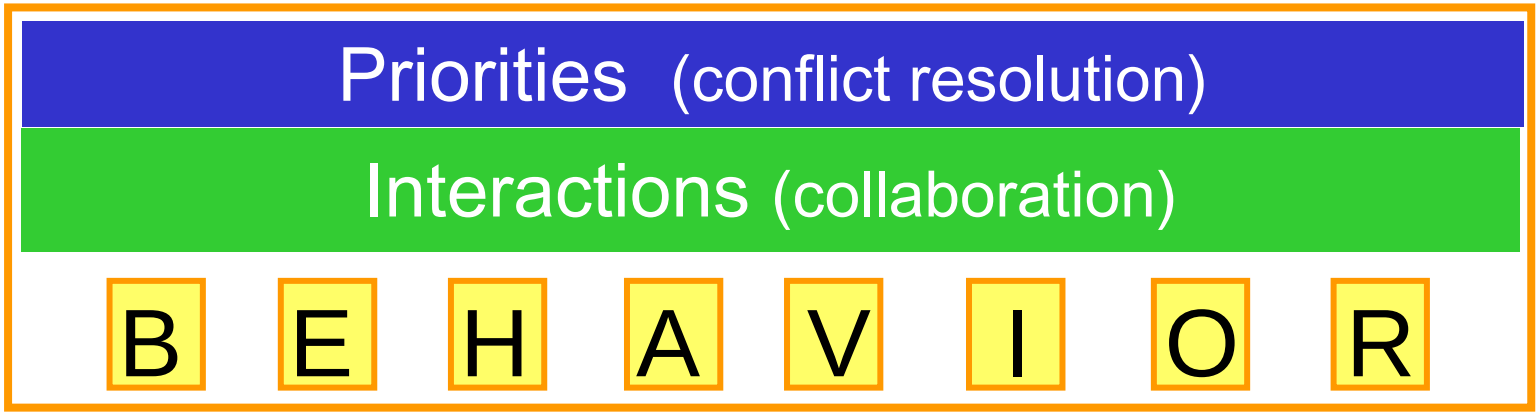
- **model-based**: the software and system descriptions used along the design flow should be based on a single semantic model. This is essential for the overall coherency and efficiency
  - Relate system descriptions and their properties for different abstraction levels and purposes (validation, performance evaluation, code generation)
- **component-based**: it provides primitives for building composite components as the composition of simpler heterogeneous components.
- **correct-by-construction**: it rely on tractable theory for guaranteeing at design time essential properties so as to avoid as much as possible monolithic *a posteriori* validation

Rigorous System Design in BIP– Design Flow

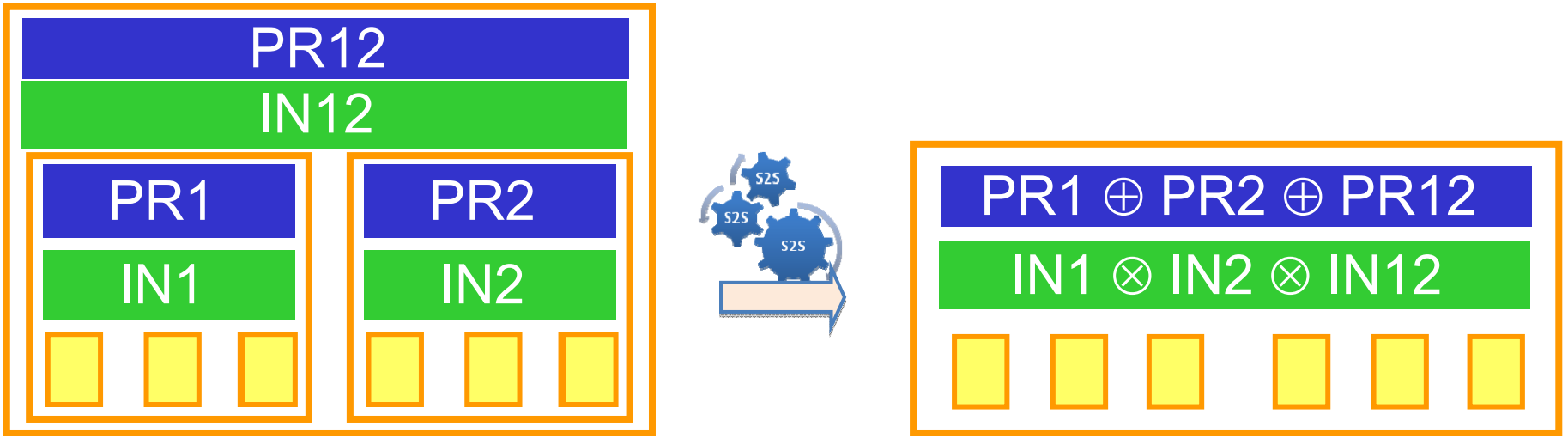


BIP – Basic Concepts

Layered component model



Composition operation parameterized by glue IN12, PR12

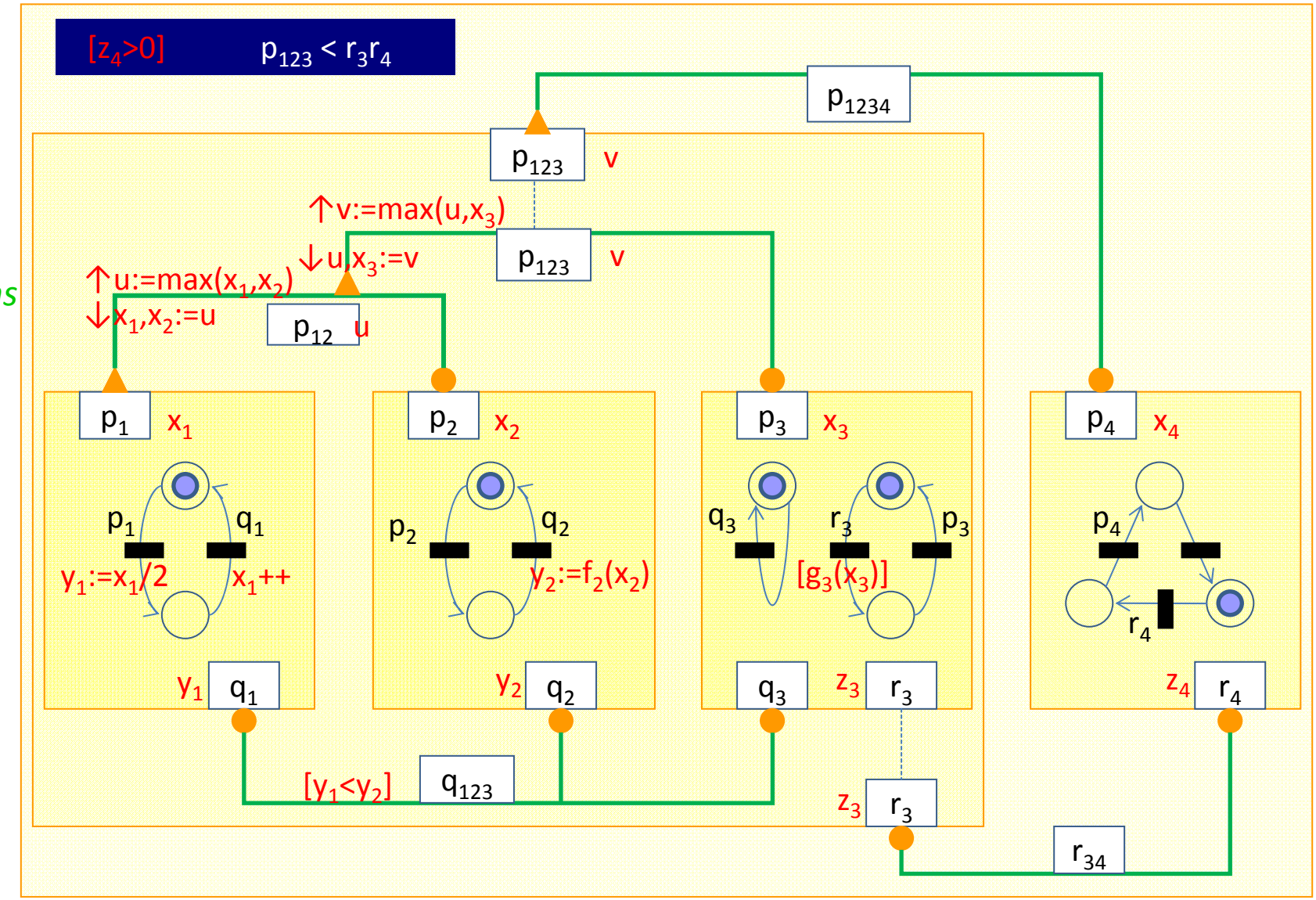


BIP in a Nutshell

Priorities

Interactions

Behavior



OVERVIEW

- Distributed Model Generation
- Monolithic code generation
- Examples
- Discussion

The S/R-BIP model

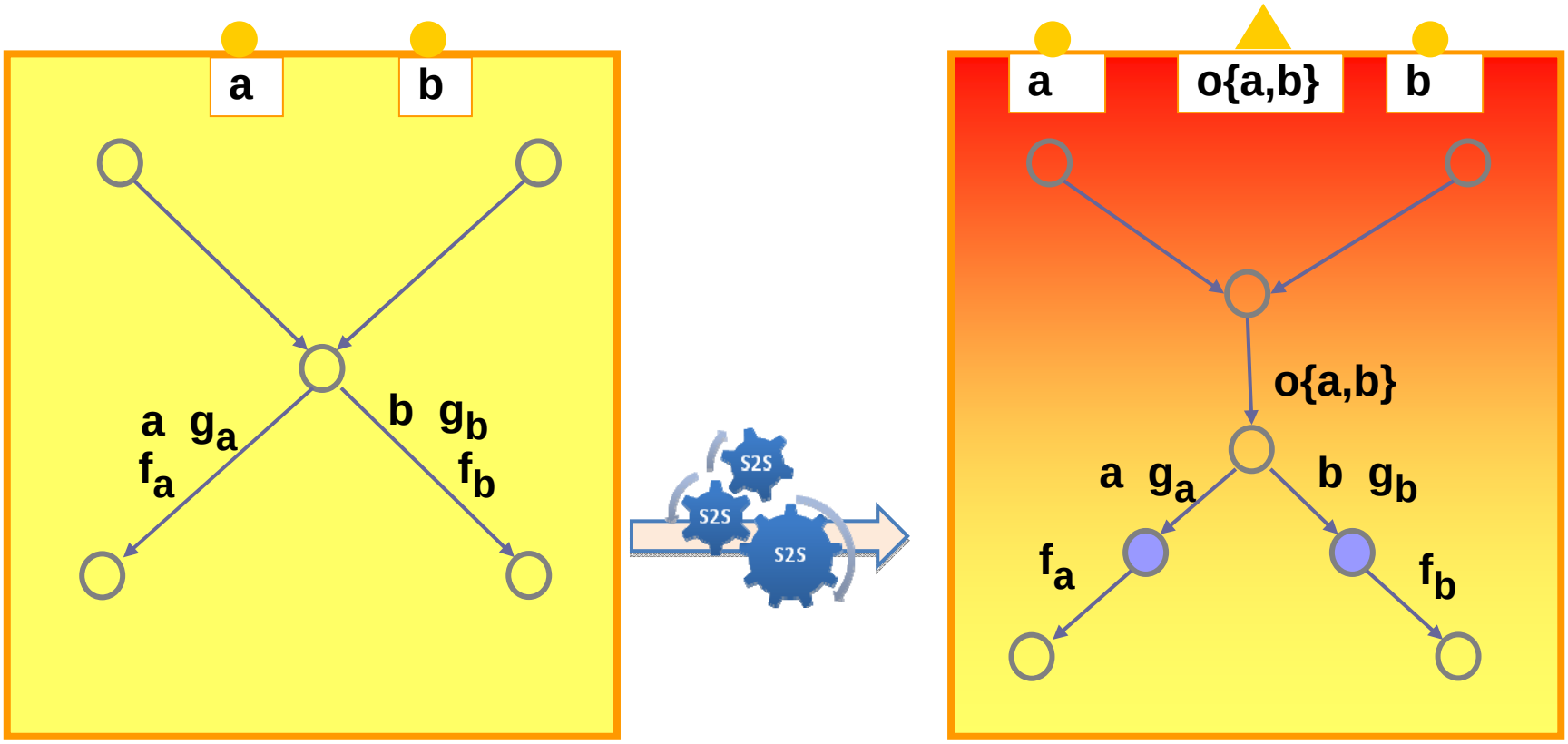
BIP is based on:

- Global state semantics, defined by operational semantics rules, implemented by the Engine
- Atomic multiparty interactions, e.g. by rendezvous or broadcast

Translate BIP models into observationally equivalent S/R-BIP models

- Collection of independent components intrinsically concurrent - No global state
  - Atomicity of transitions is broken by separating interaction from internal computation
- Point to point communication by asynchronous message passing
- Translation is correct-by-construction

From BIP to S/R-BIP – Atomic Components



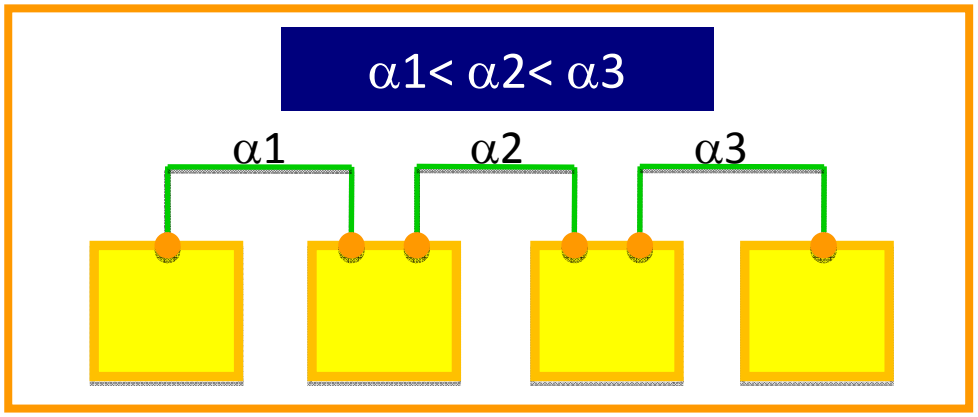
Global state model

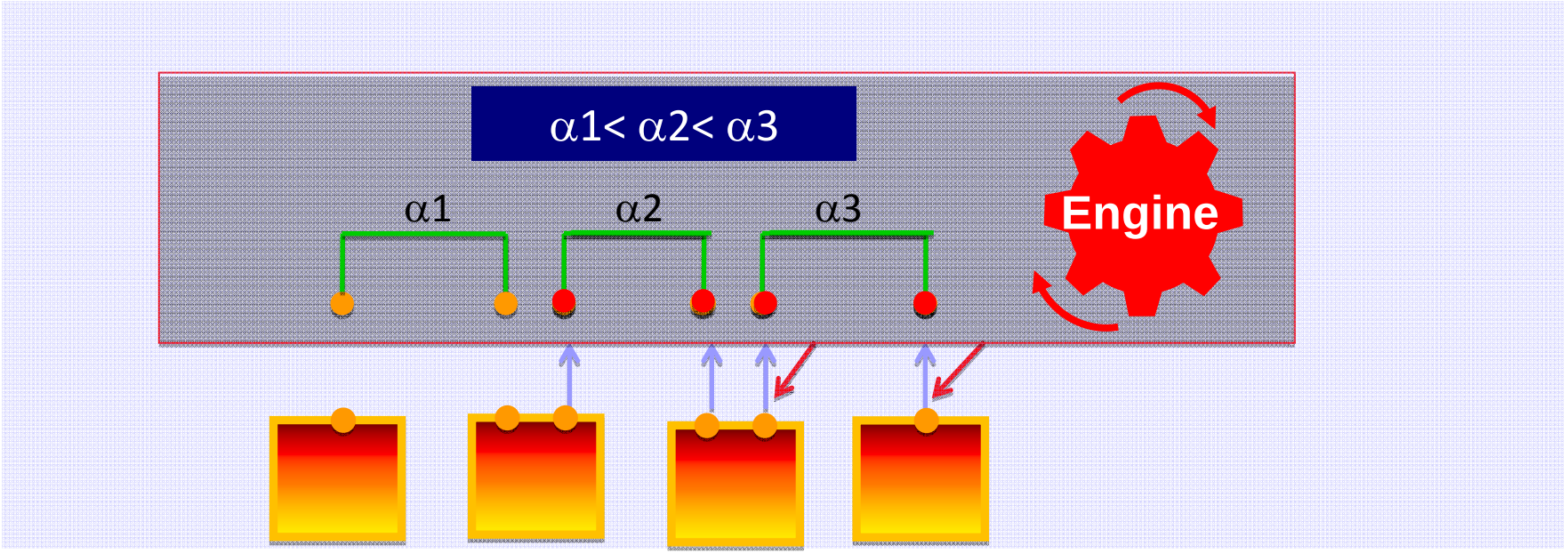
Partial state model

- Before reaching a ready state, the set of the enabled ports is sent to the Engine
- From a ready state, await notification from the Engine indicating the selected port

Single Engine (Forte 2008)

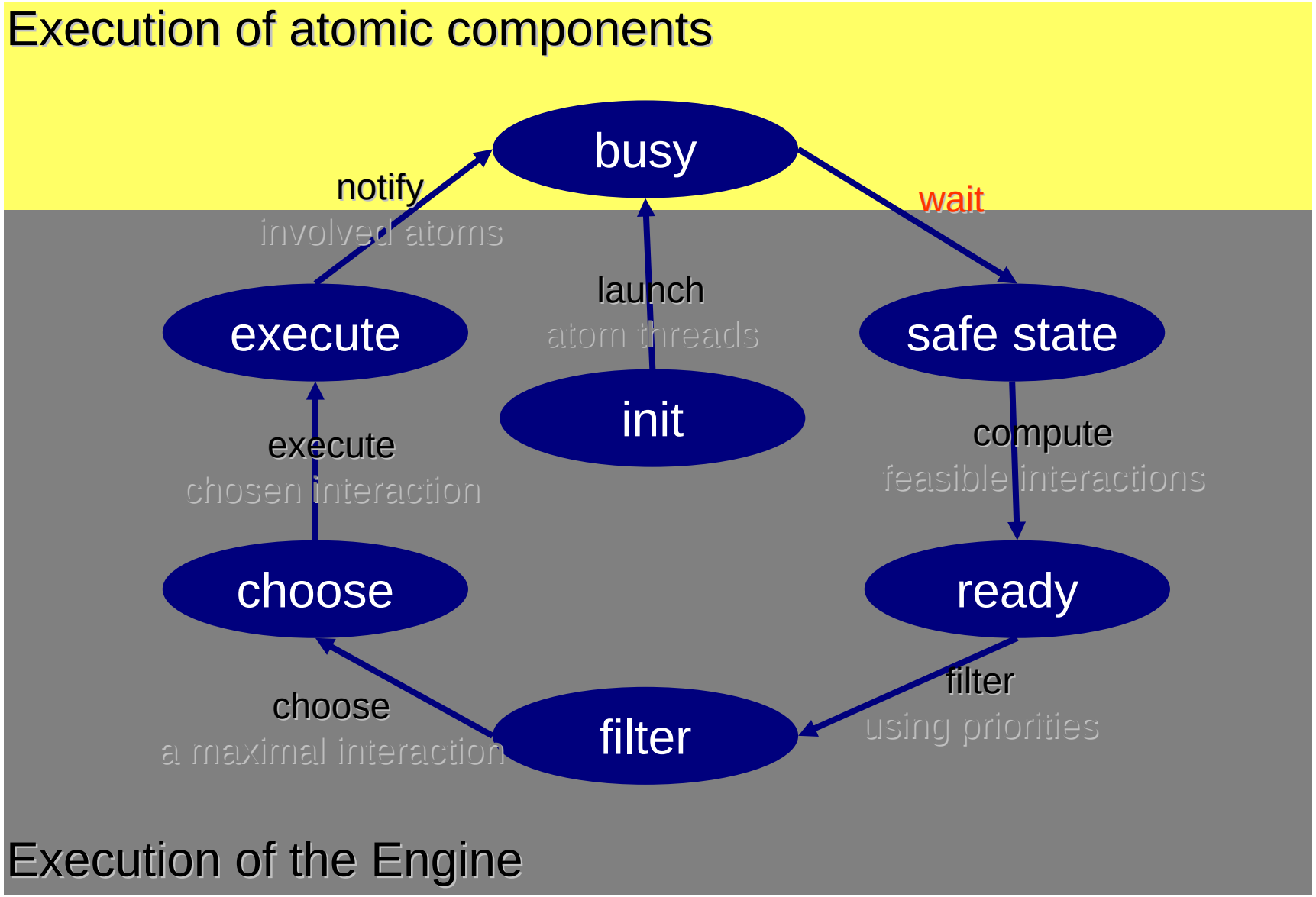
BIP Model





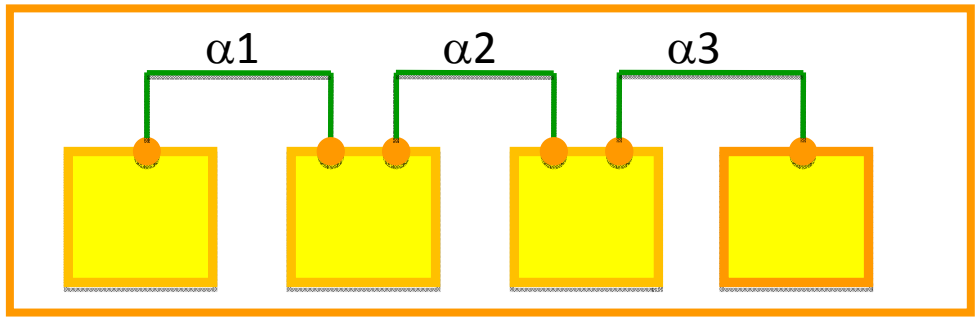
One Engine executes *all* interactions !

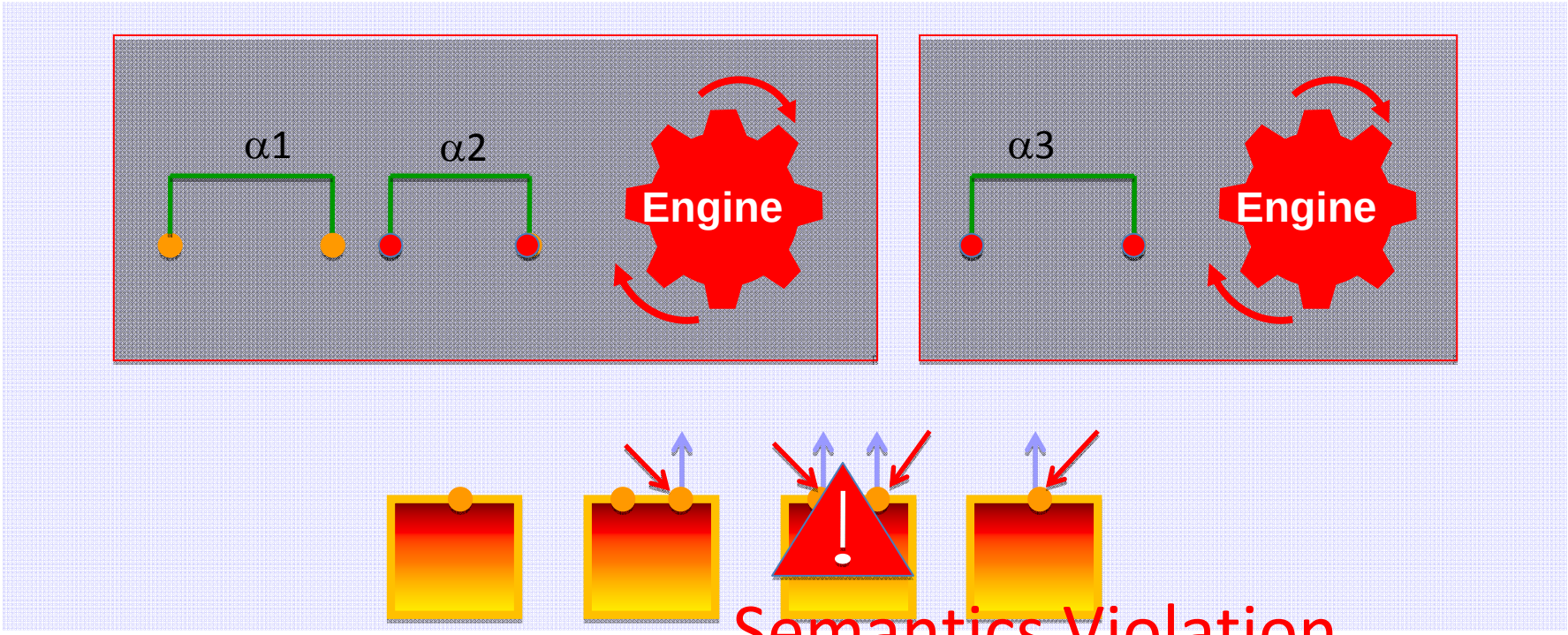
Single Engine Execution



Multiple Engines

BIP Model

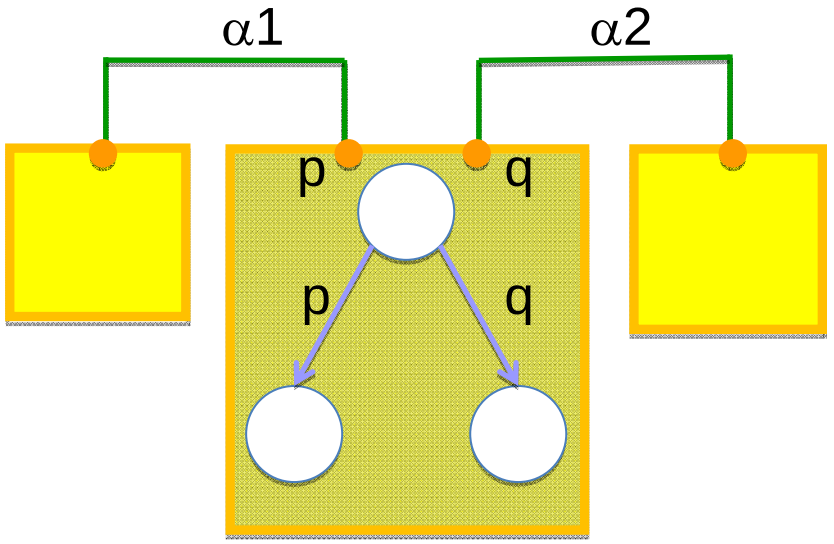




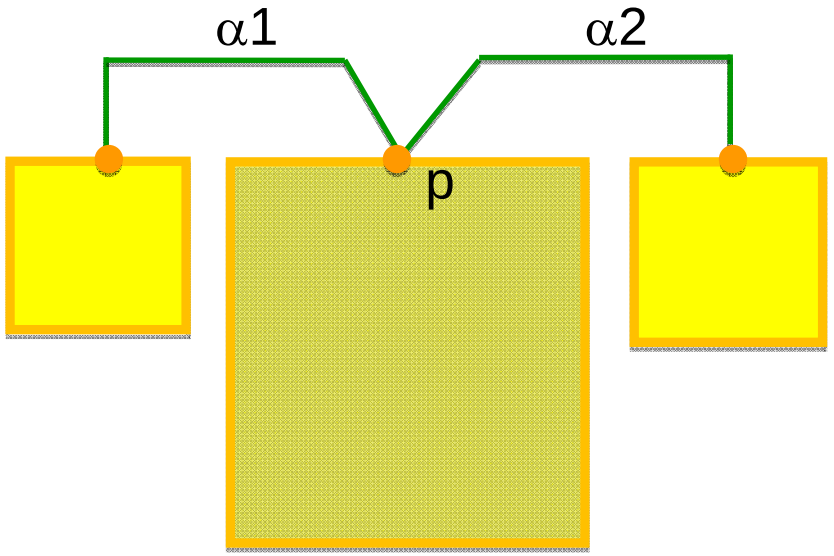
Semantics Violation

Dispatch interactions across *multiple* engines !

Multiple Engines – Conflicting Interactions



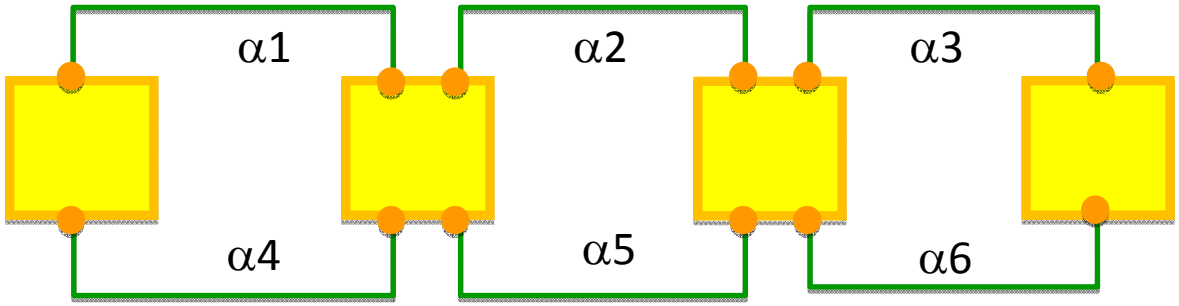
α1 and α2 depend on conflicting transitions



α1 and α2 share a common port p

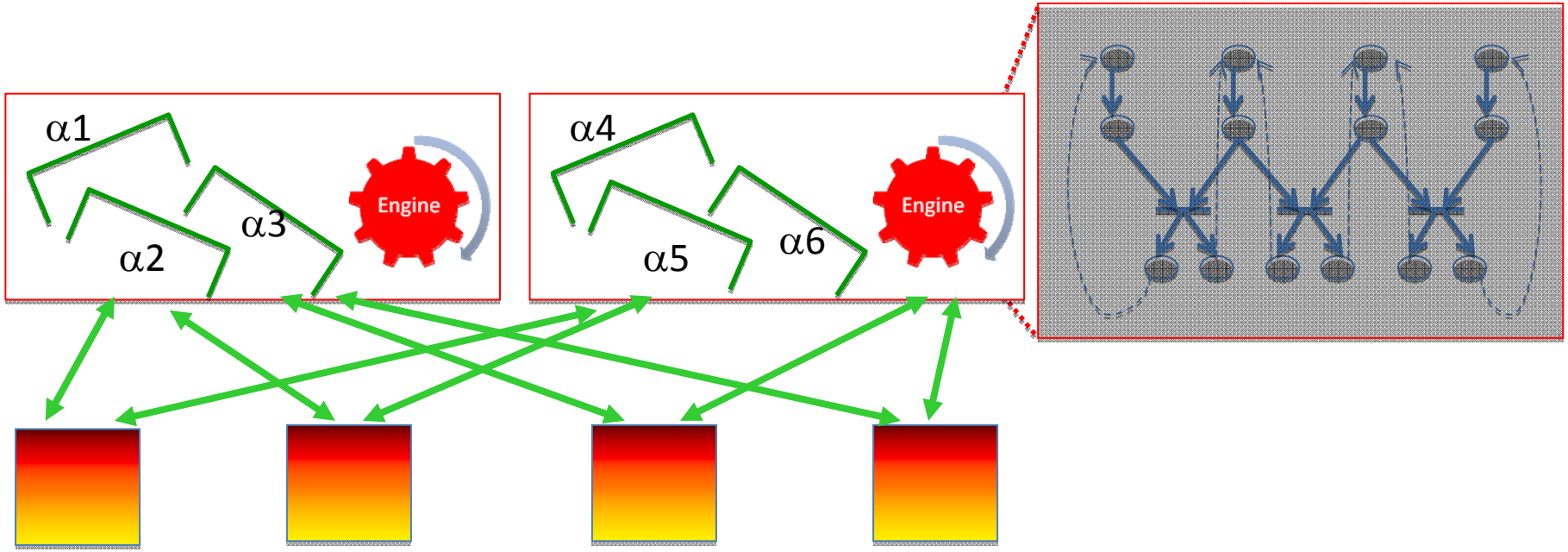
α1 # α2: the interactions α1 and α2 may be in conflict

Conflict-Free Multiple Engines



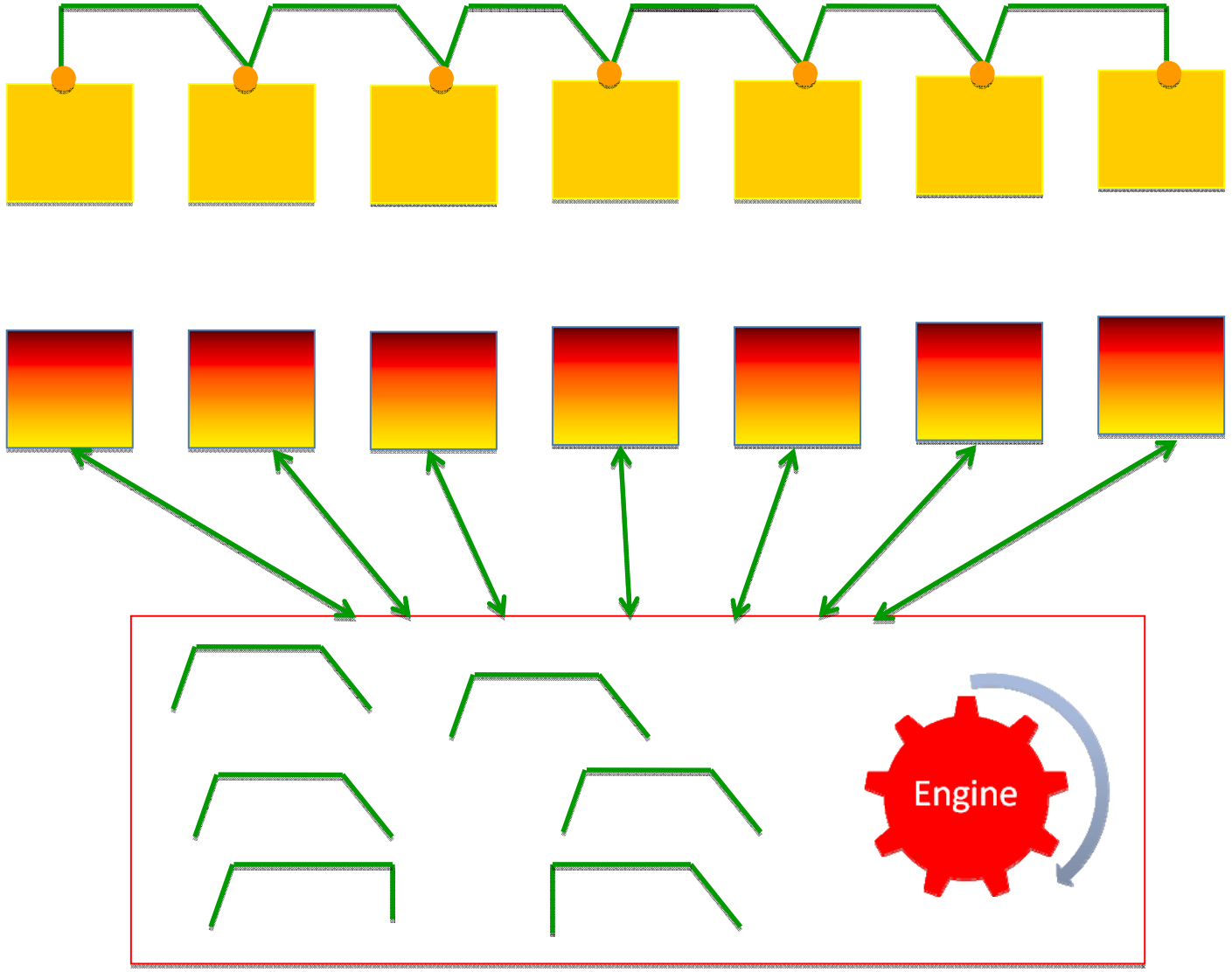
α1 # α2 # α3

α4 # α5 # α6



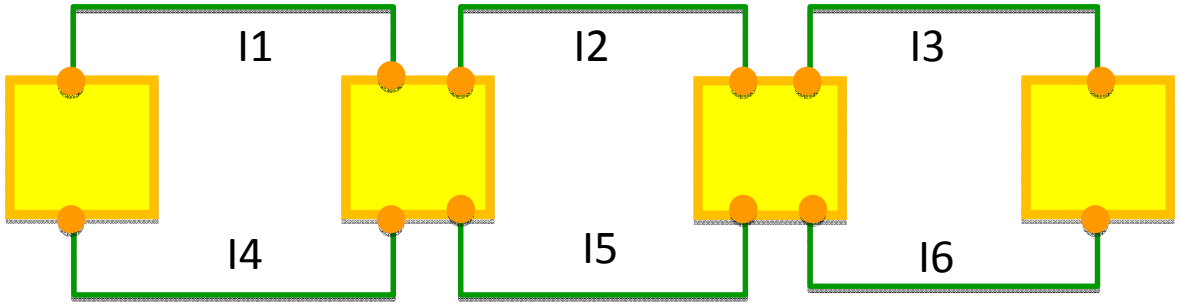
Each engine handles interactions of a class of #*

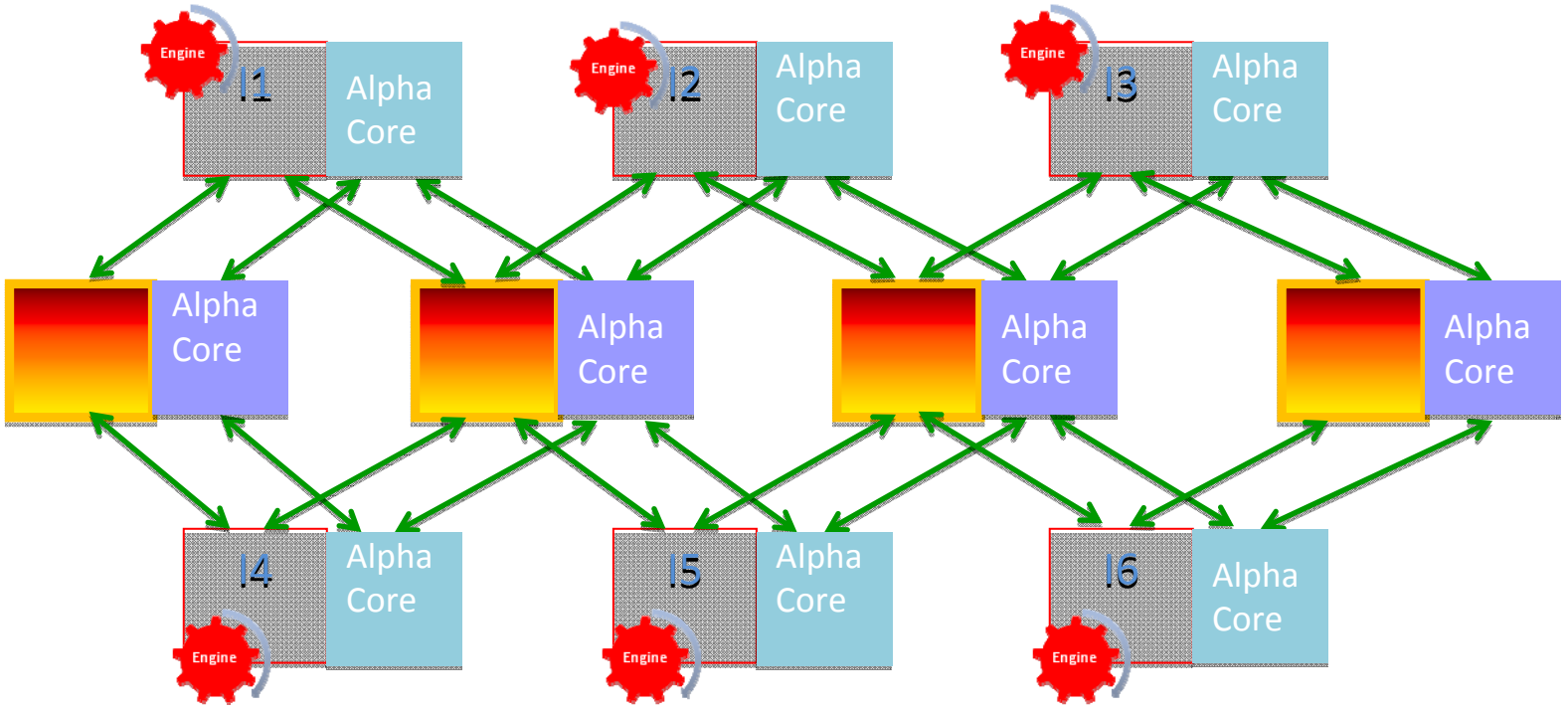
Conflict-Free Multiple Engines – Problem



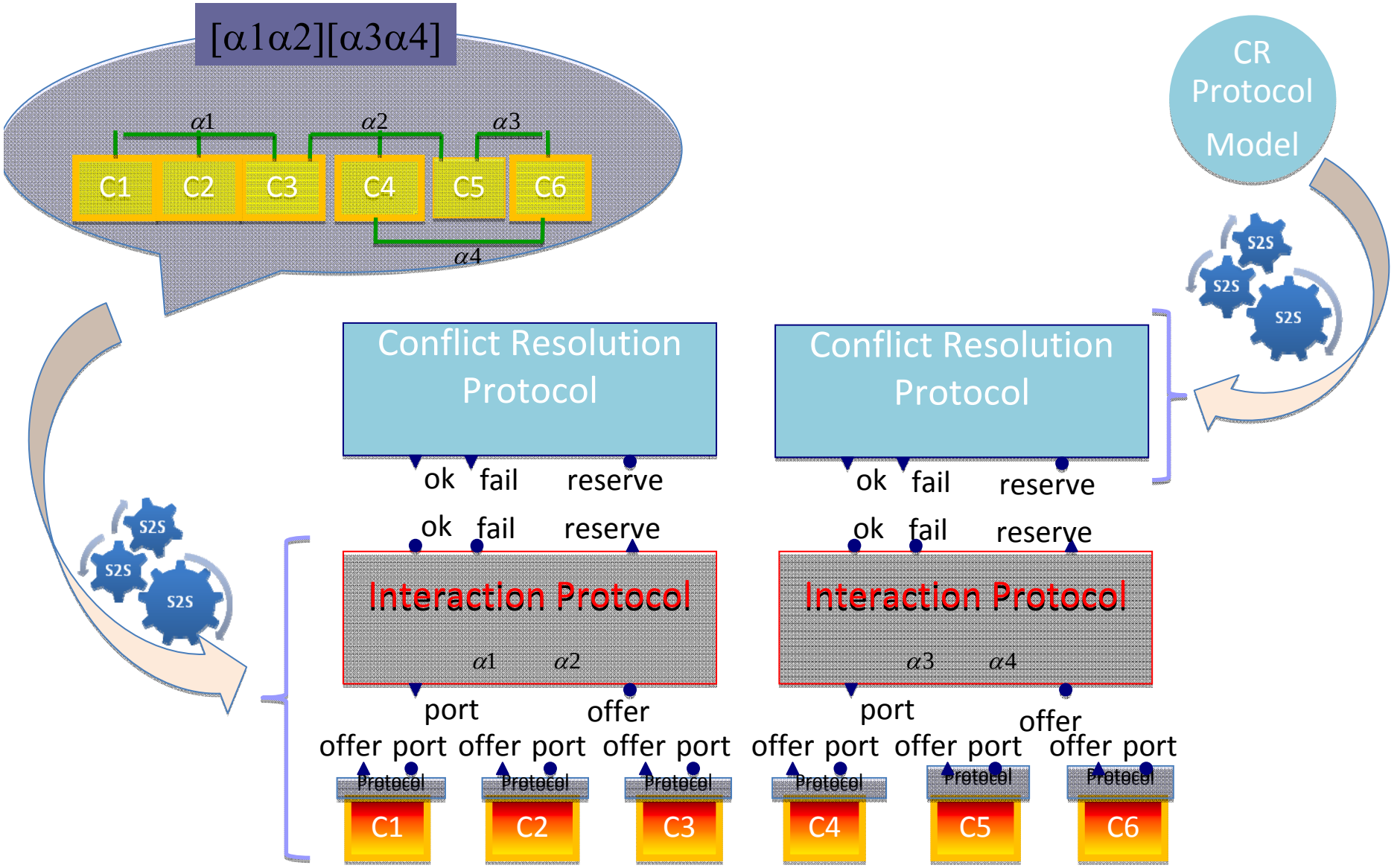
- Taking #* may reduce drastically parallelism between interactions

Multiple Engines - Using the AlphaCore Protocol

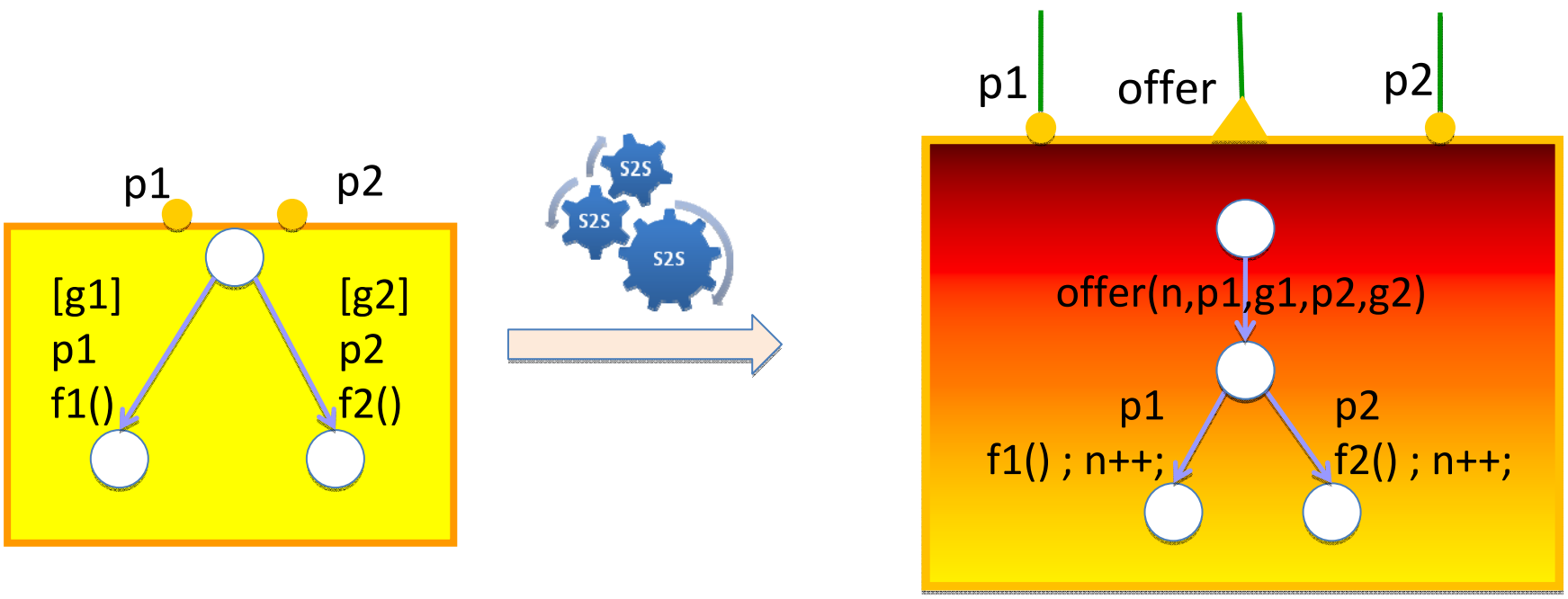




3-Layer Architecture

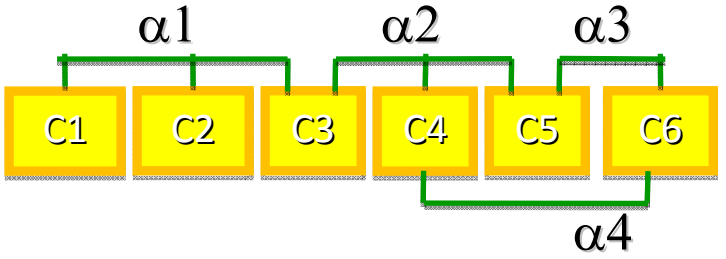


3-Layer Architecture – Atomic Components



n: counts the number
of executed transitions

3 Layer Architecture – Centralized CRP



Centralized Conflict Resolution Protocol

reserve2 ok2 fail2 reserve3 ok3 fail3 reserve4 ok4 fail4

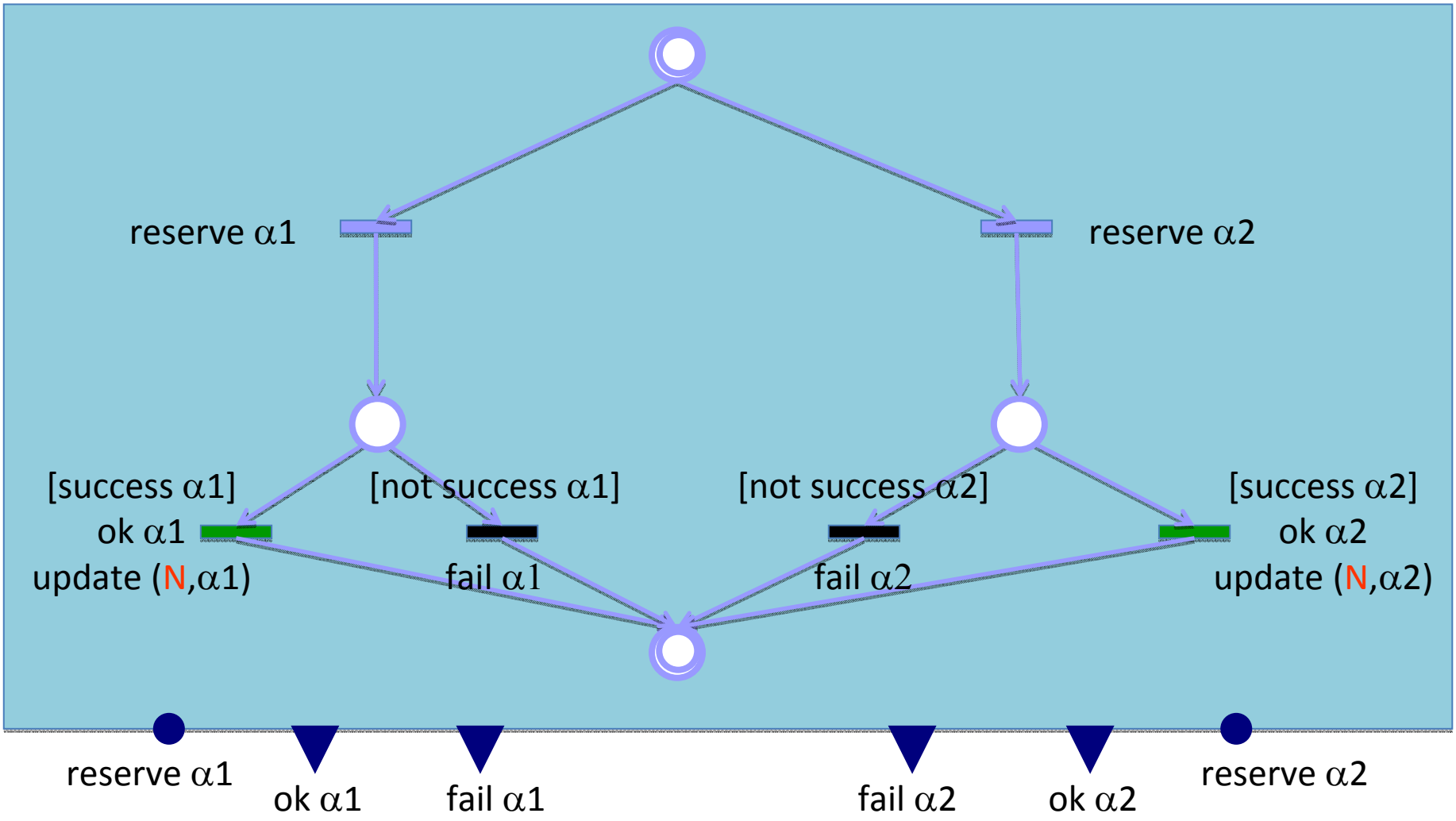
$\alpha 1$ Interaction Protocol $\alpha 2$

$\alpha 3$ Interaction Protocol $\alpha 4$

o1 p1 o2 p2 o3 p3 p4 o41 o42 p5 p6 o51 o52 p7 p8 o6 p5 p6

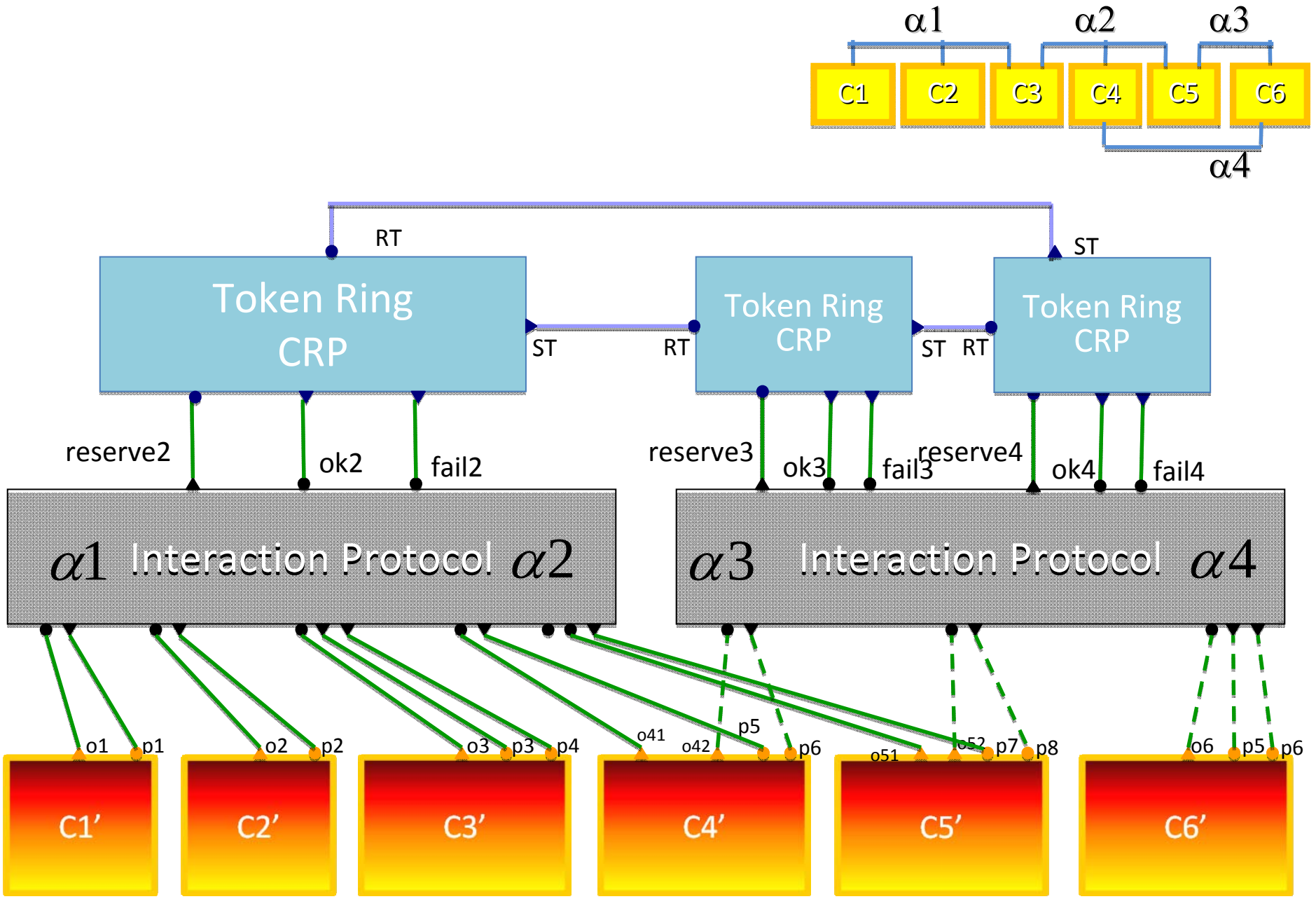
C1' C2' C3' C4' C5' C6'

3-Layer Architecture – Centralized CRP

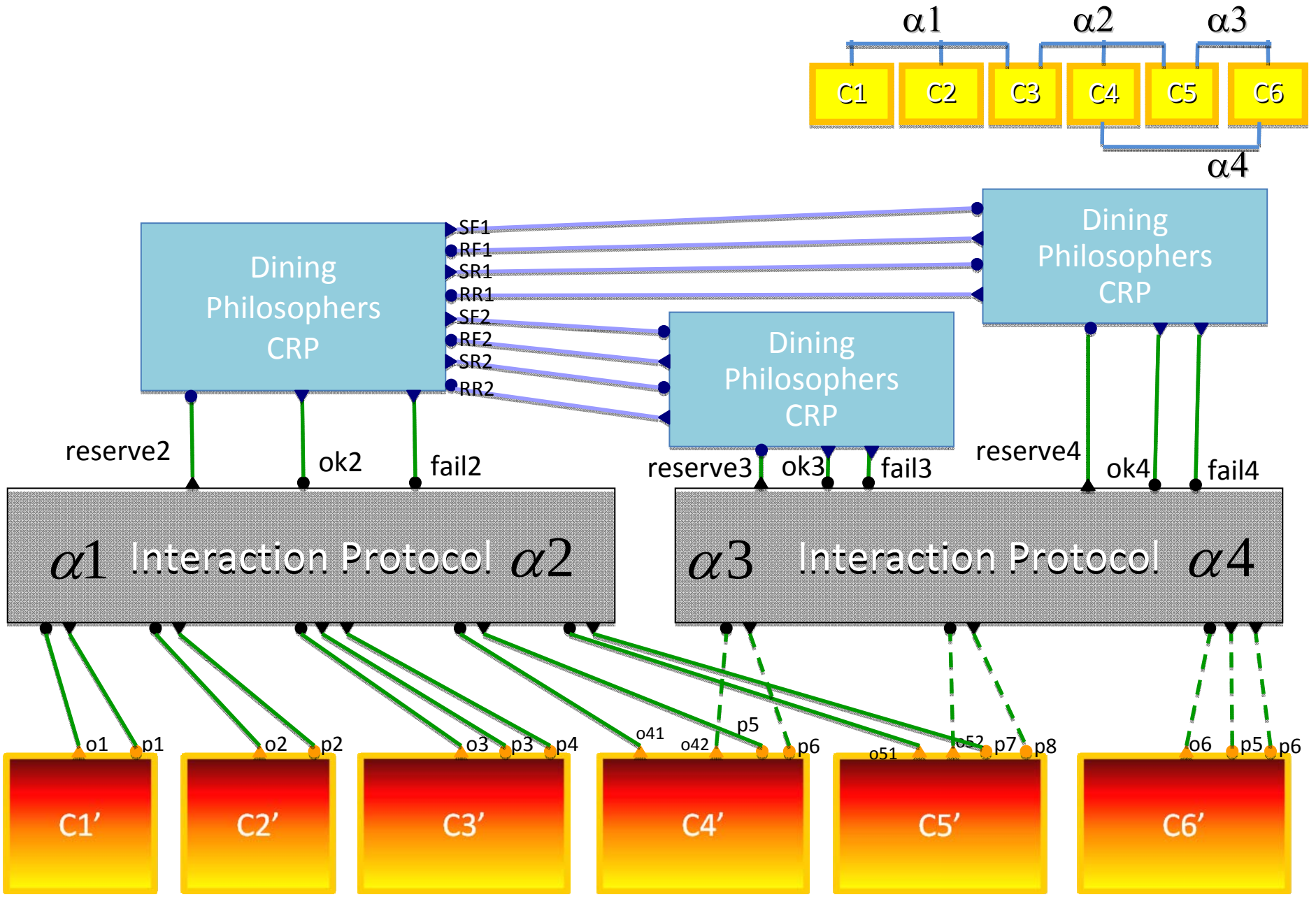


N=[N1, …, Nk]: keeps track of the state of the counters n of the components

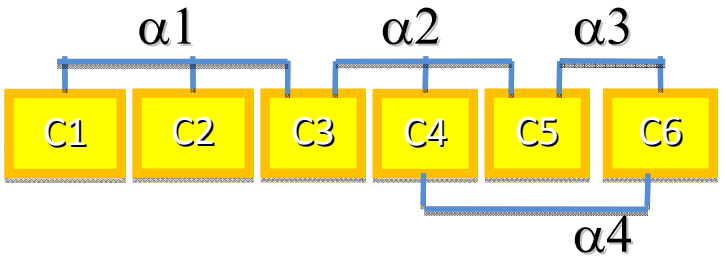
3-Layer Architecture – Token Ring CRP

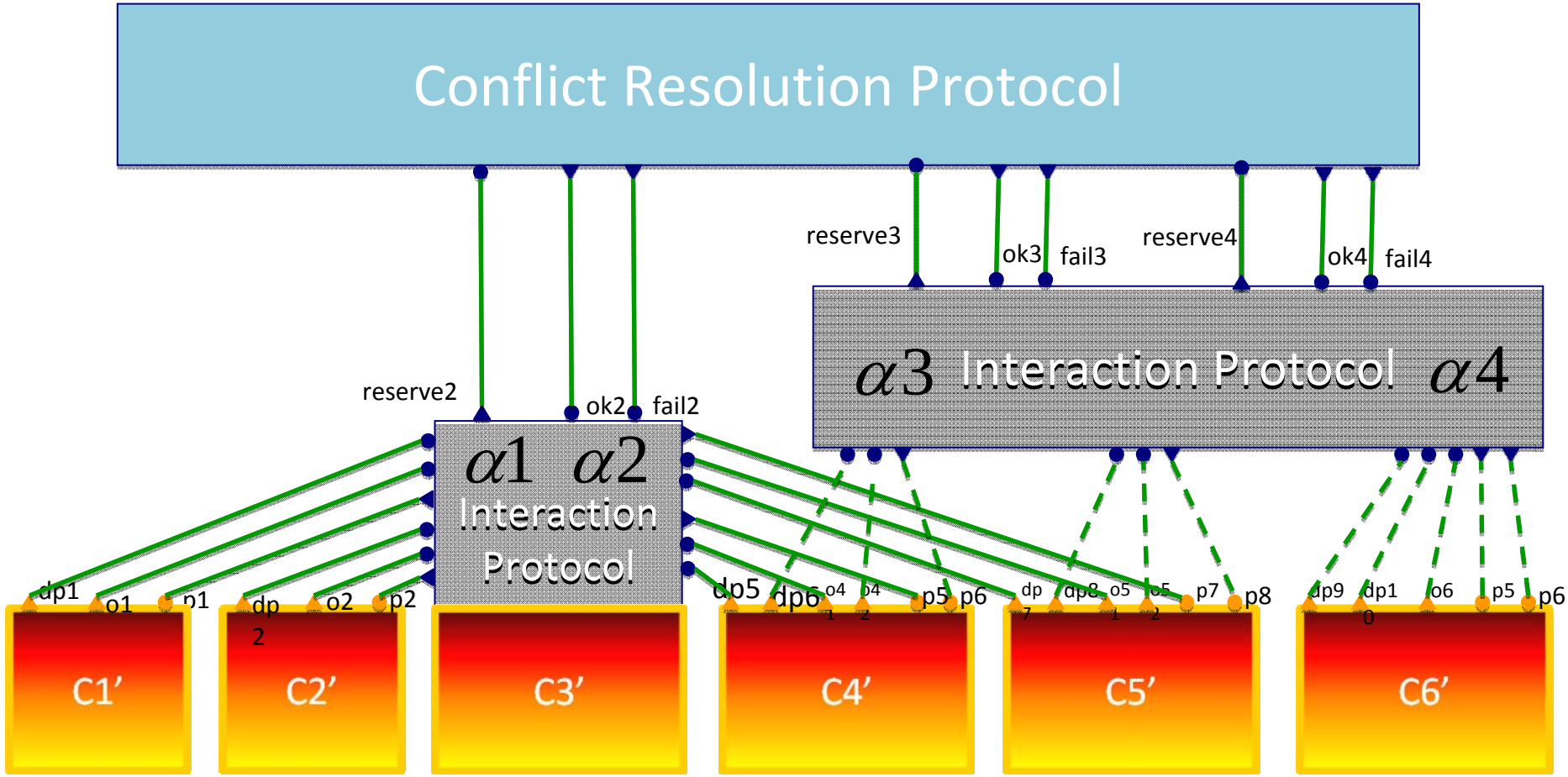


3-Layer Distributed BIP – Dining Philosophers CRP



Monolithic Code Generation – Component Partitioning





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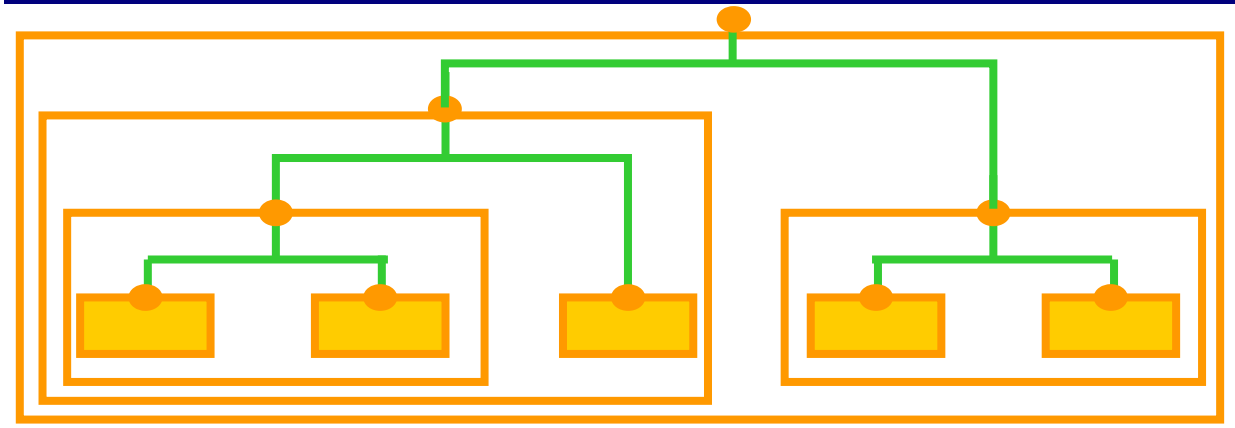
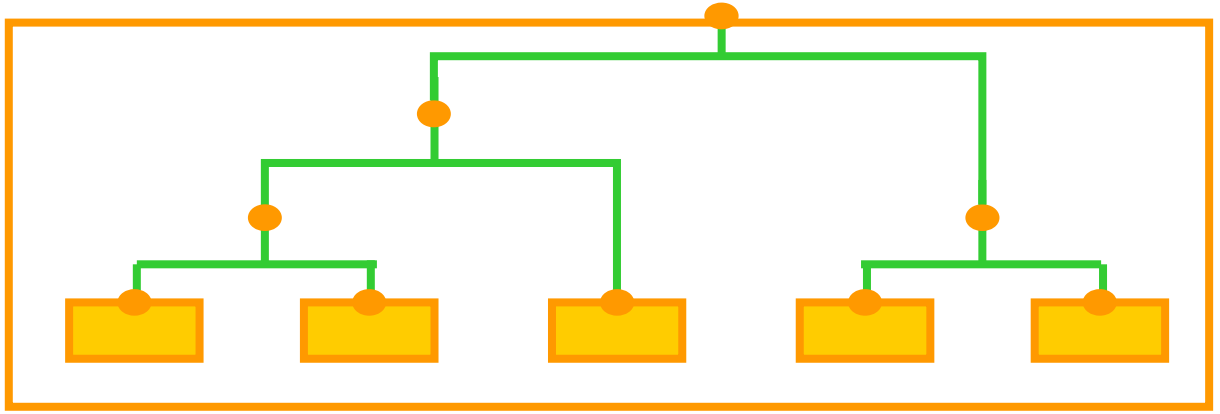
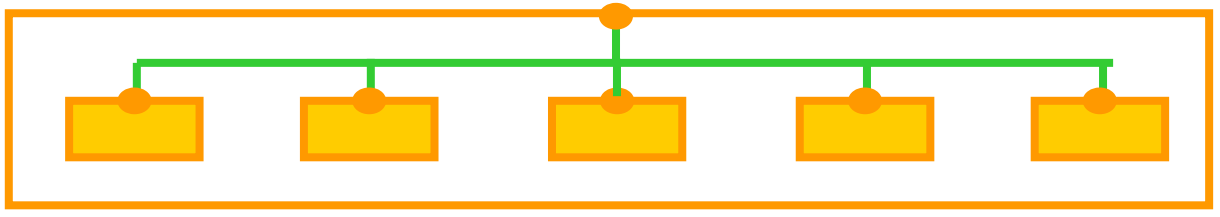
From Composite Components to C code



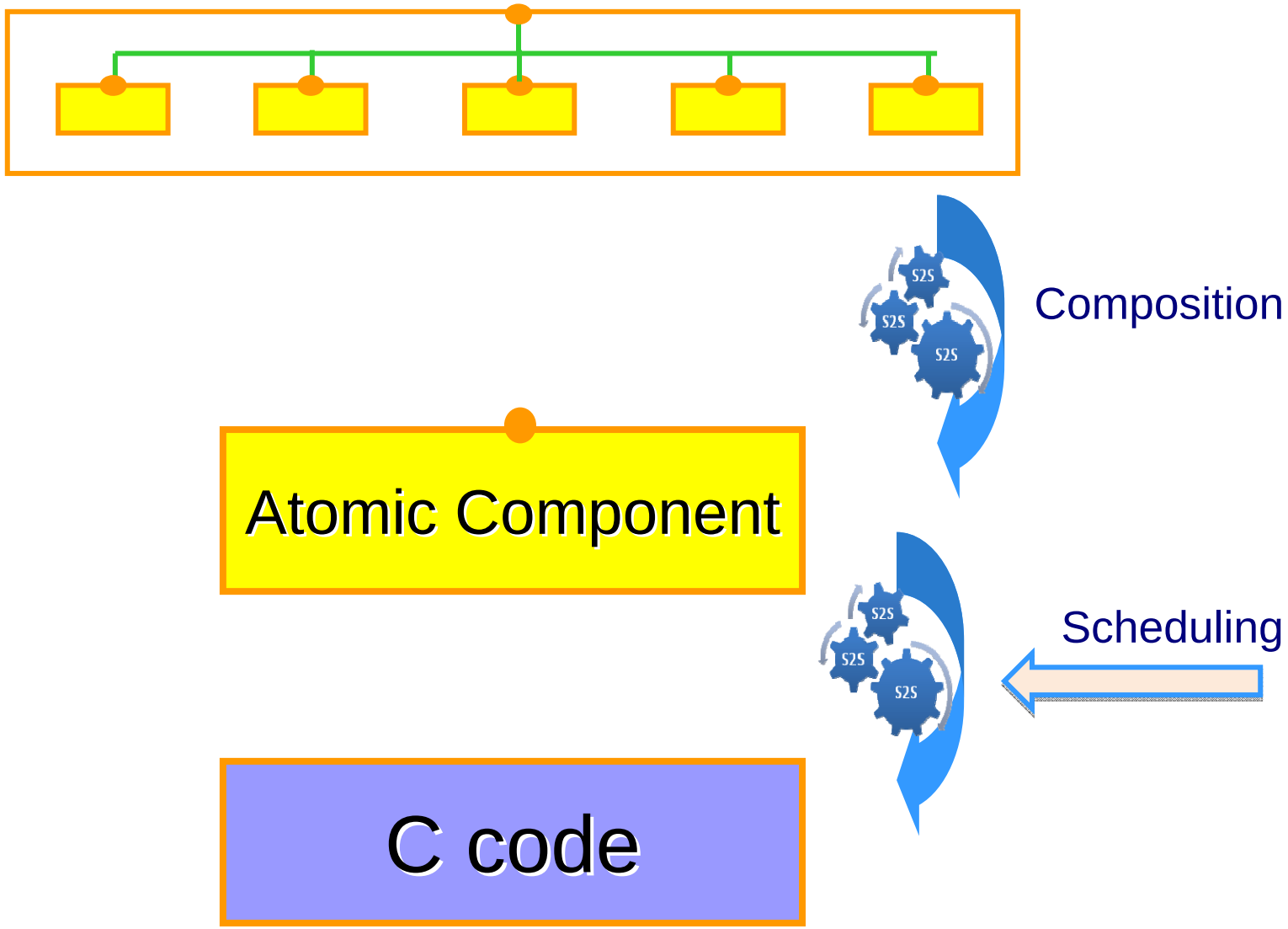




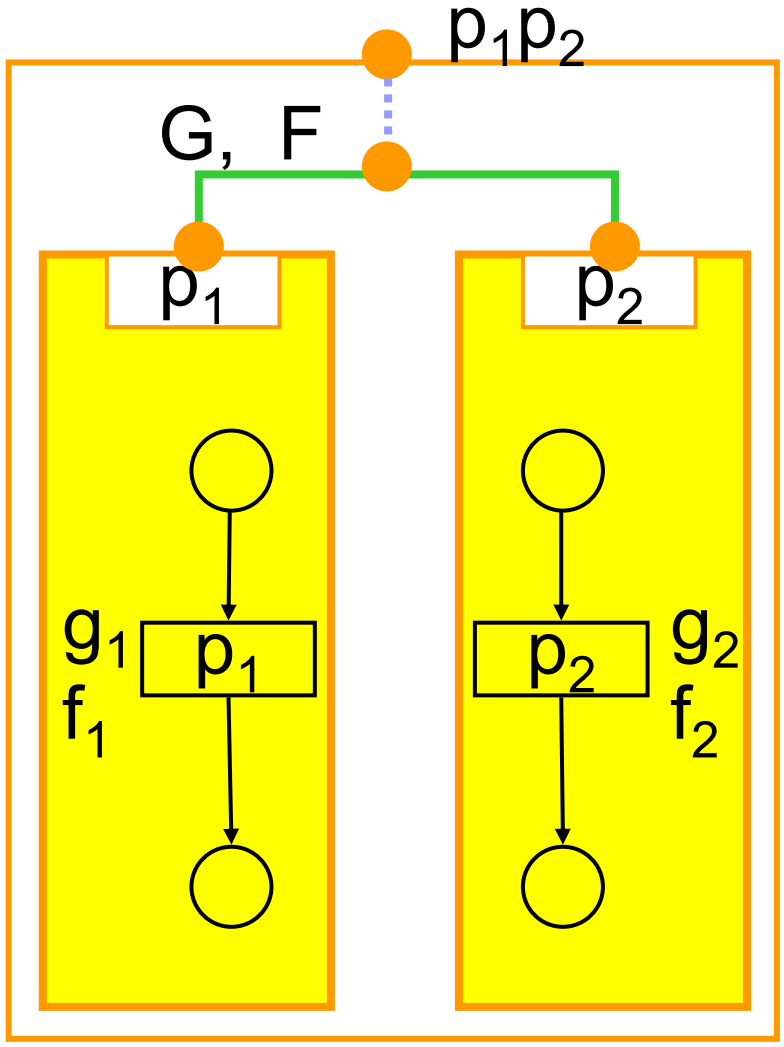
Component Flattening

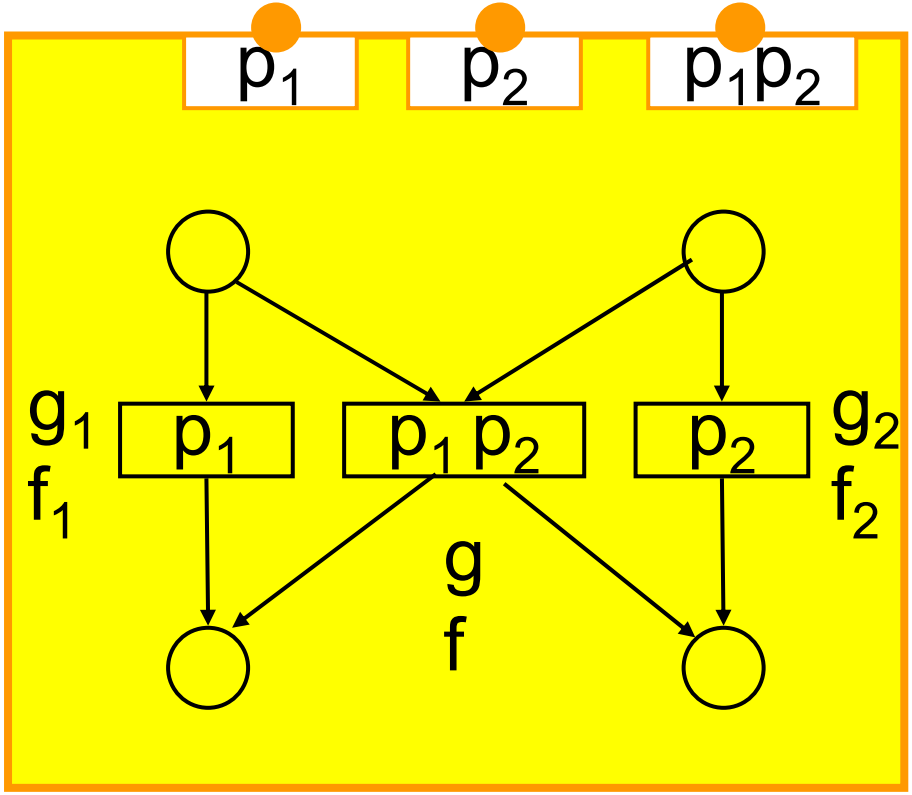
Connector Flattening

From Composite to Monolithic C code



From Composite to Monolithic Components– Composition





Composition

$g = g_1 \wedge g_2 \wedge G$

$f = F;(f_1 || f_2)$

Example – MPEG4 Video Encoder

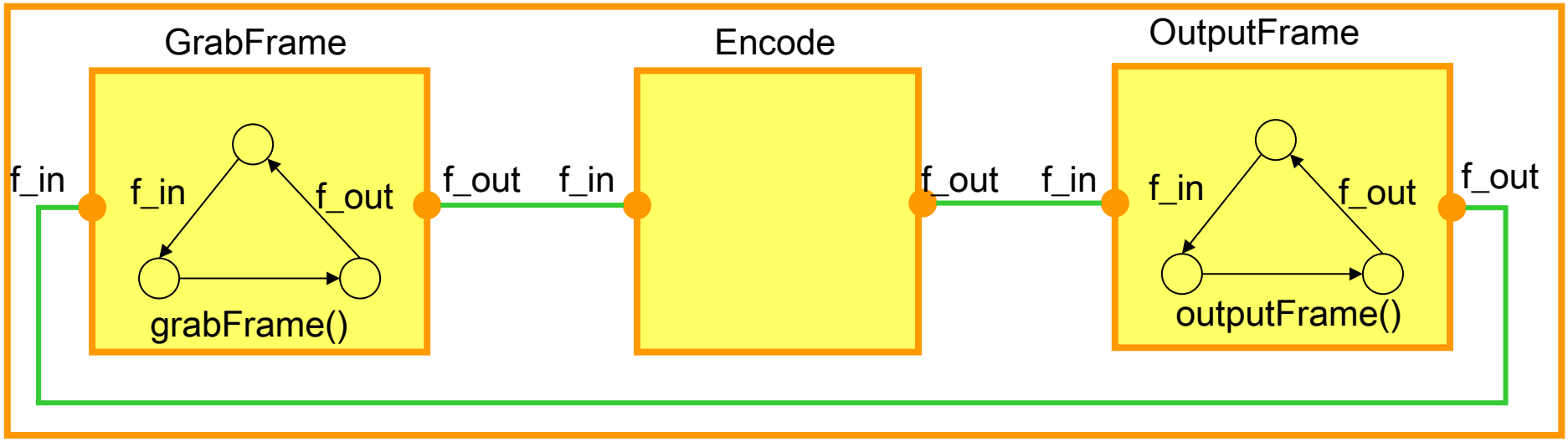
Transform the monolithic sequential program (12000 lines of C code) into a componentized one:

++ reusability, schedulability analysis, reconfigurability

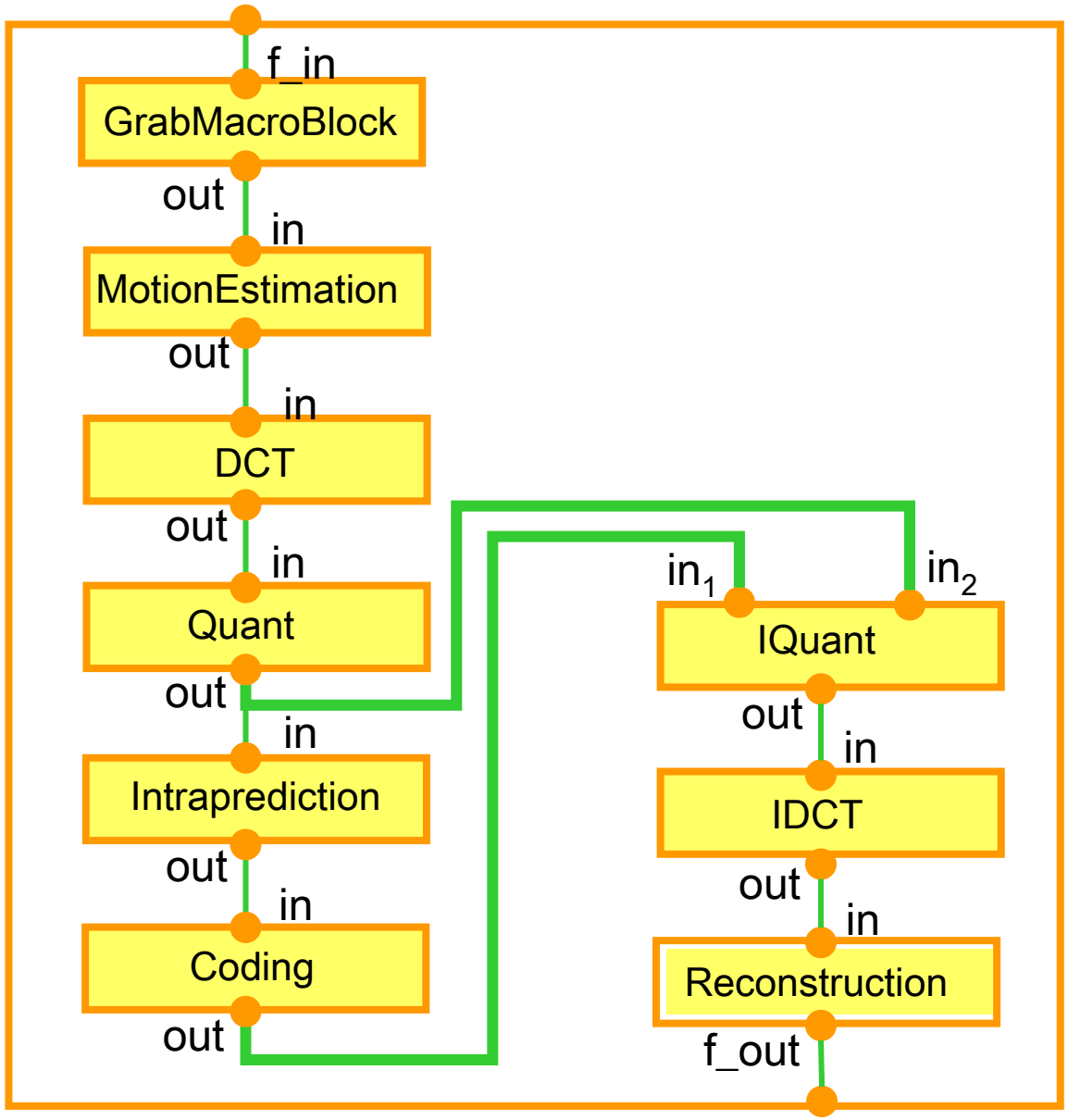
– – overhead in memory and execution time

Decomposition:

- GrabFrame: gets a frame and produces macroblocks
- OutputFrame: produces an encoded frame
- Encode: encodes macroblocks



Example – MPEG4 Video Encoder

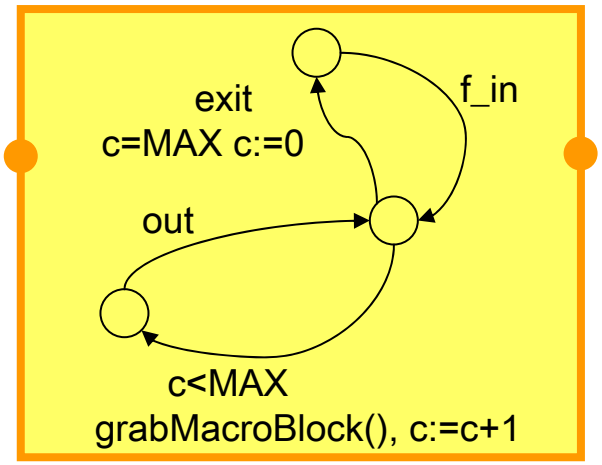


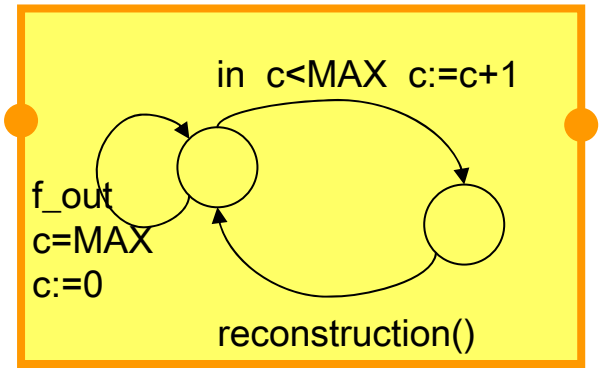
GrabMacroBlock: splits a frame in (W*H)/256 macro blocks, outputs one at a time

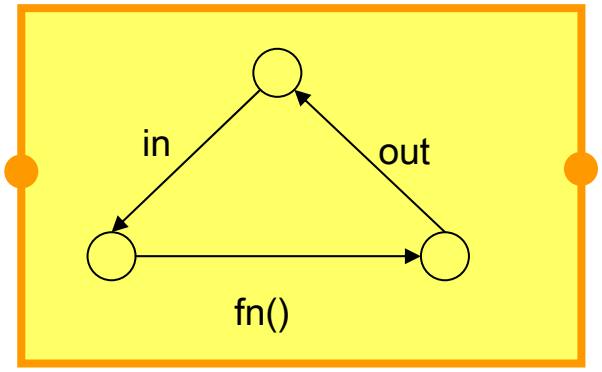
Reconstruction: regenerates the encoded frame from the encoded macro blocks.

: buffered connections

Example – MPEG4 Video Encoder







MAX=(W*H)/256
W=width of frame
H=height of frame

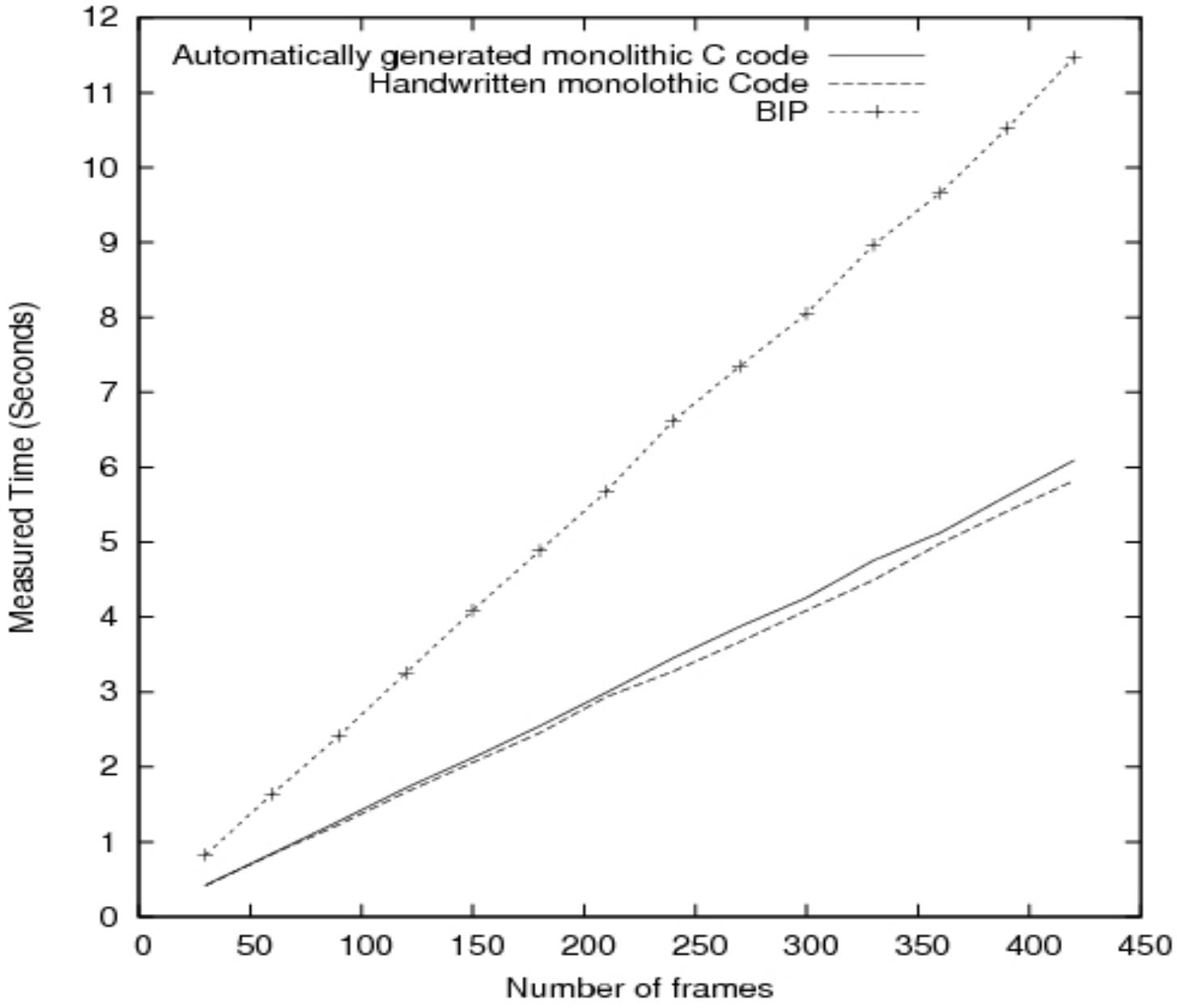
Example – MPEG4 Video Encoder: Results

- ~ 500 lines of BIP code
  - Consists of 20 atomic components and 34 connectors
  - Components call routines from the encoder library
- The generated C++ code from BIP is ~ 2,000 lines
- BIP binary is 288 KB compared to 172 KB of monolithic binary

100% overhead in execution time wrt monolithic code

- ~66% due to computation of interactions (can be reduced by composing components)
- ~34% due to evaluation of priorities (can be reduced by applying priorities to atomic components)

Source-to-Source – MPEG4 Video Encoder: Results



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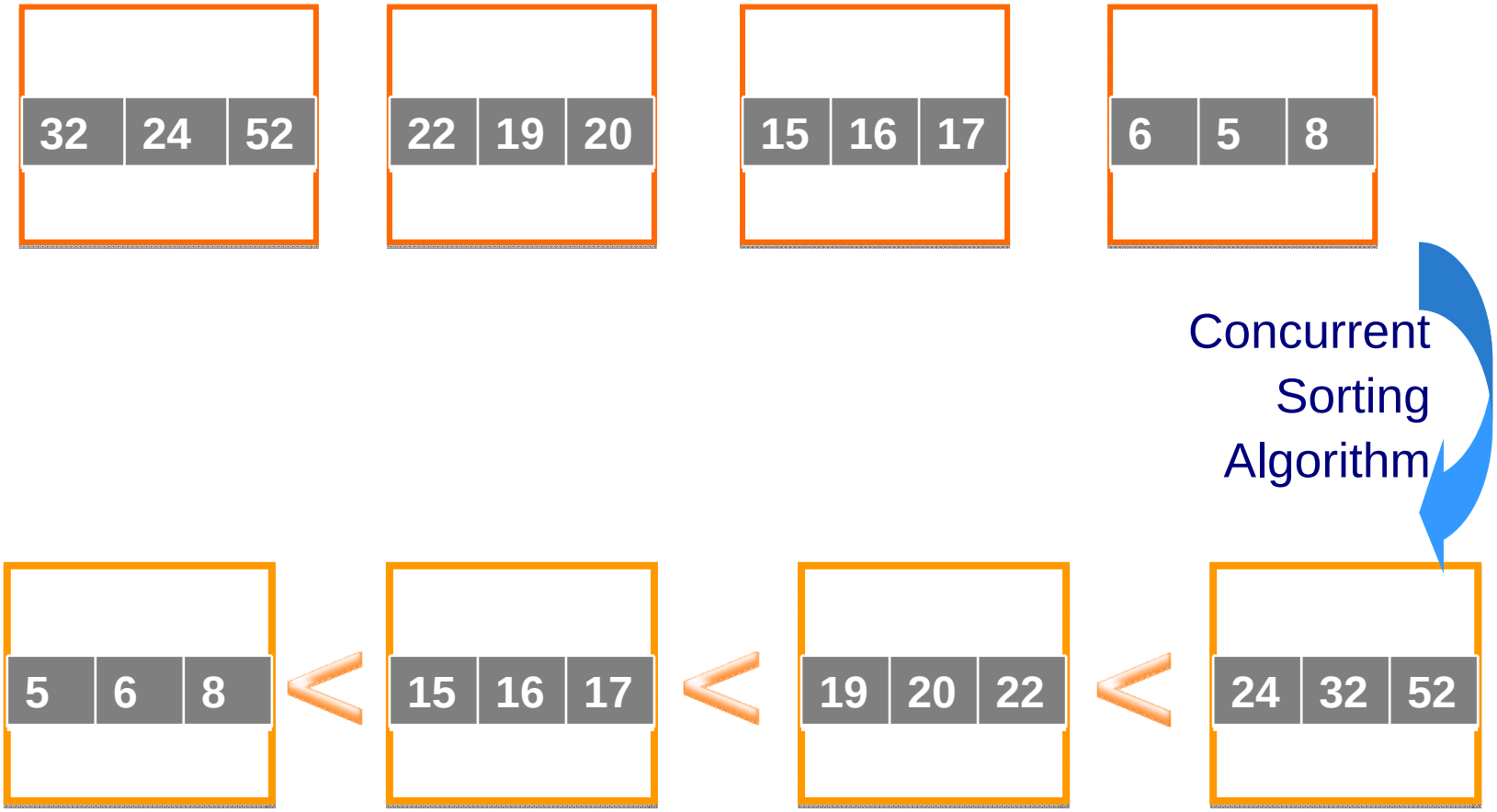
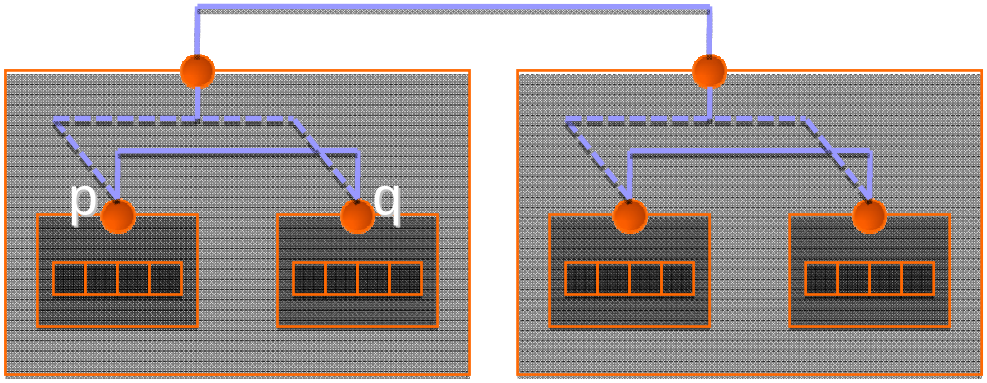
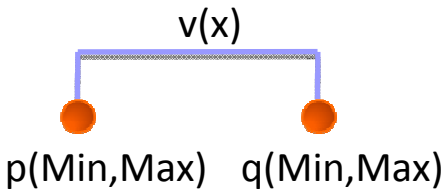
Concurrent Sorting

Inspired from a network sorting algorithm

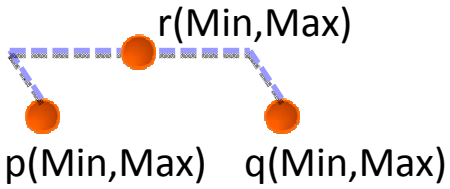


Concurrent Sorting

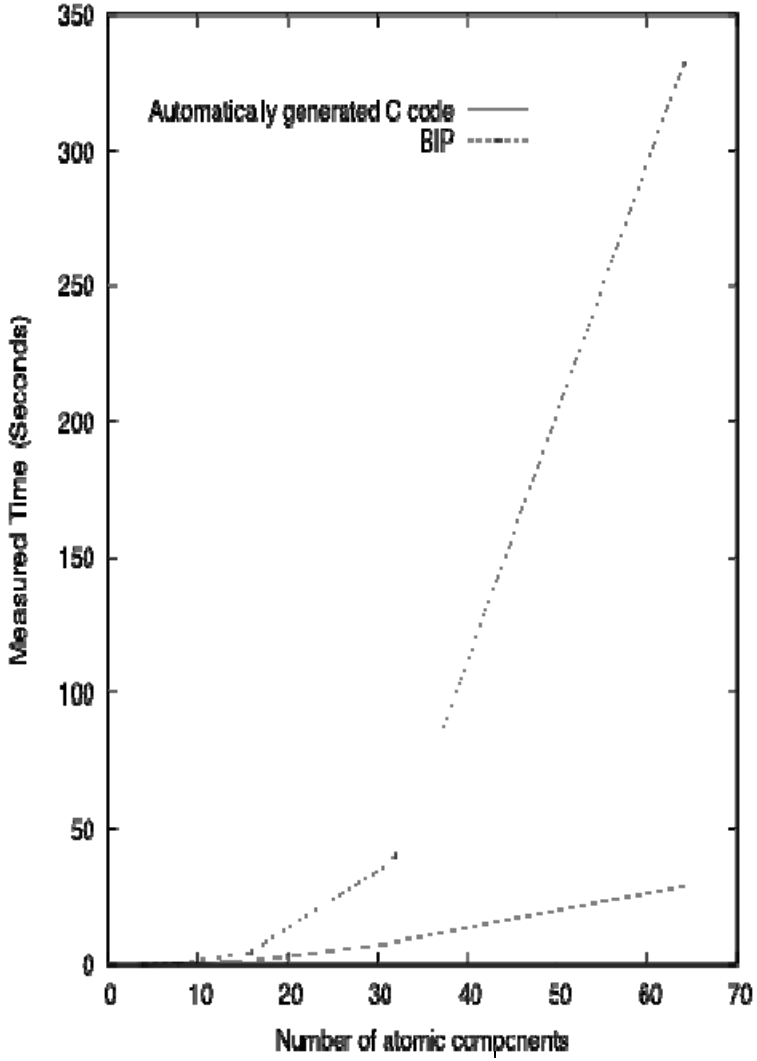




G: p.Max > q.Min
U: none
D: x:= p.Max ; p.Max:=q.Min; q.Min:=x

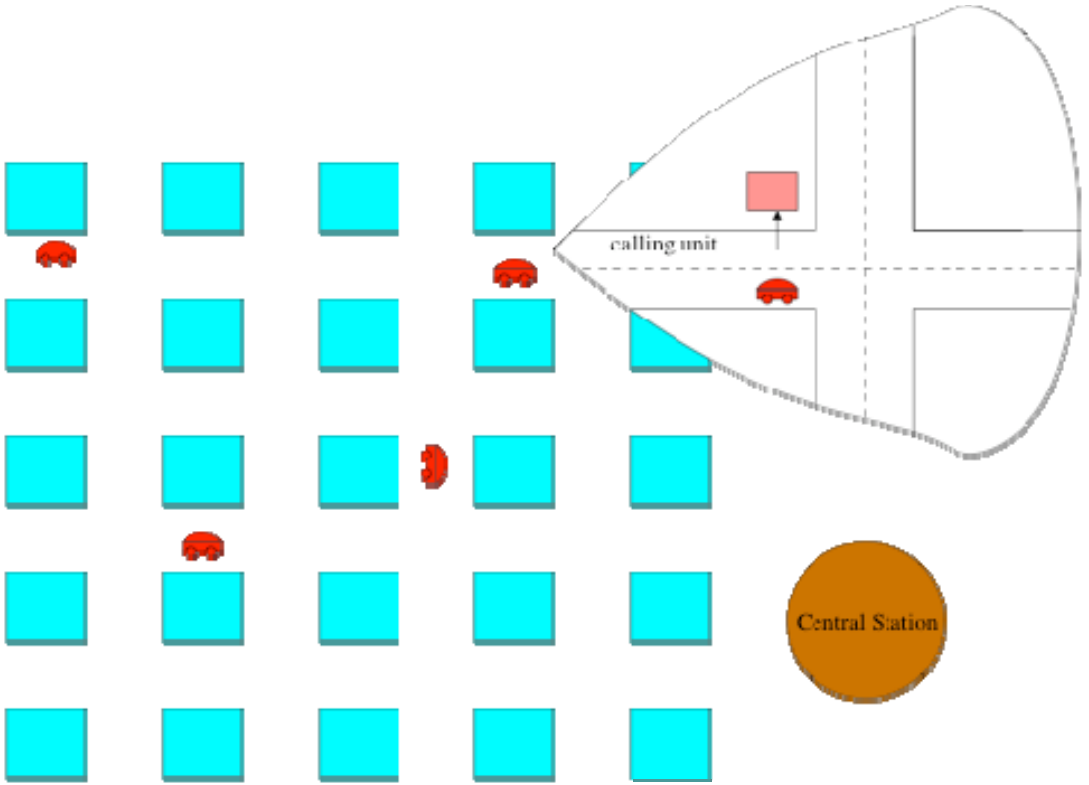


G : p.Max <= q.Min
U : Min := p.Min;Max := q.Max
D : p.Min := Min; q.Max := Max

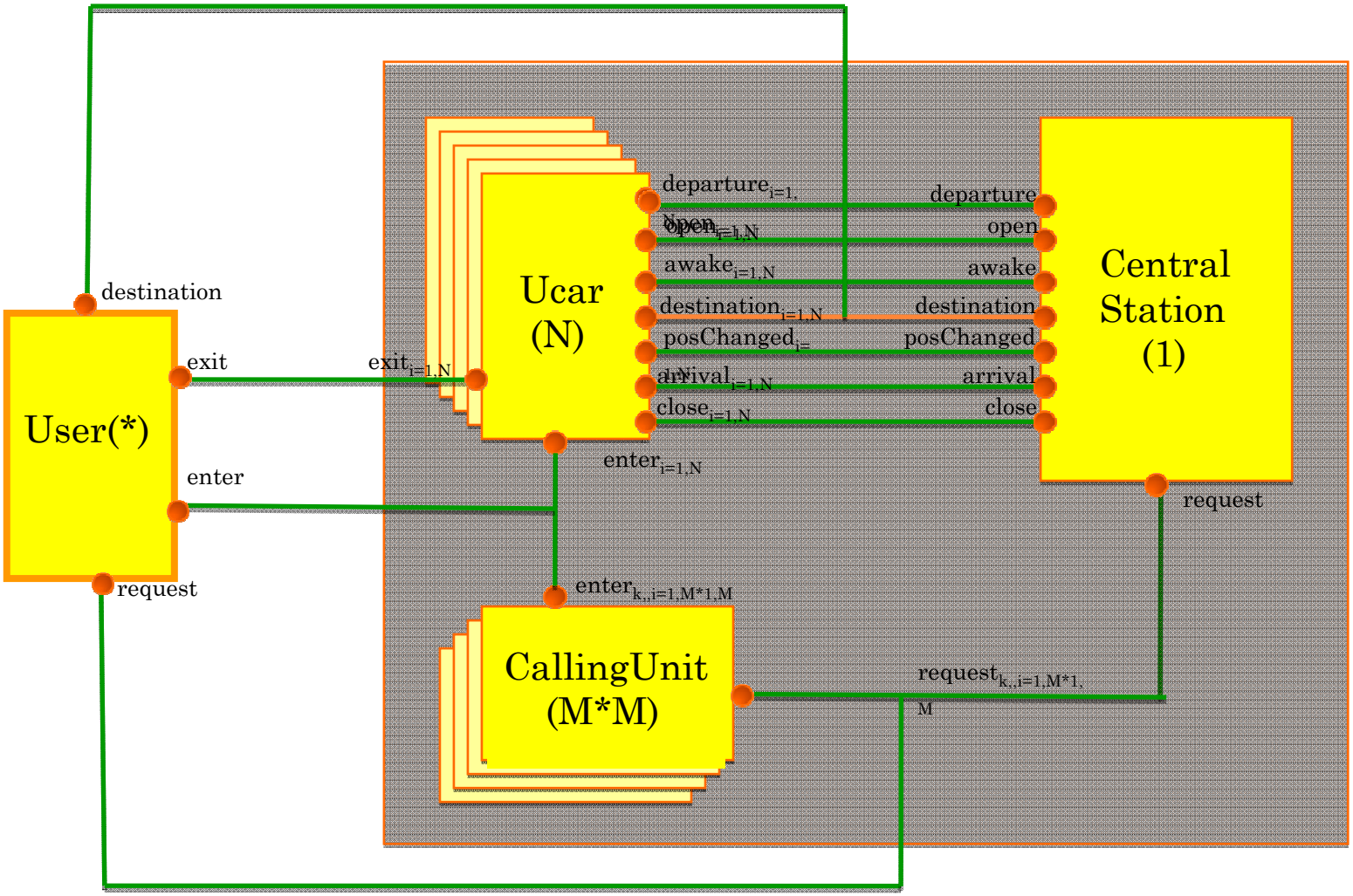


UTOPAR

- UTOPAR is an automated transportation system managing various requests for transportation
- Industrial case study of the Combest Project



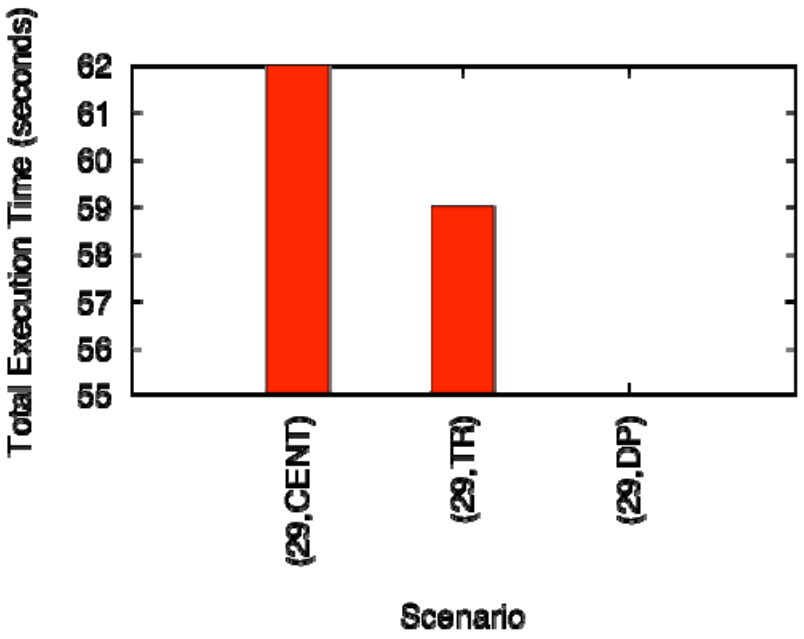
UTOPAR in BIP



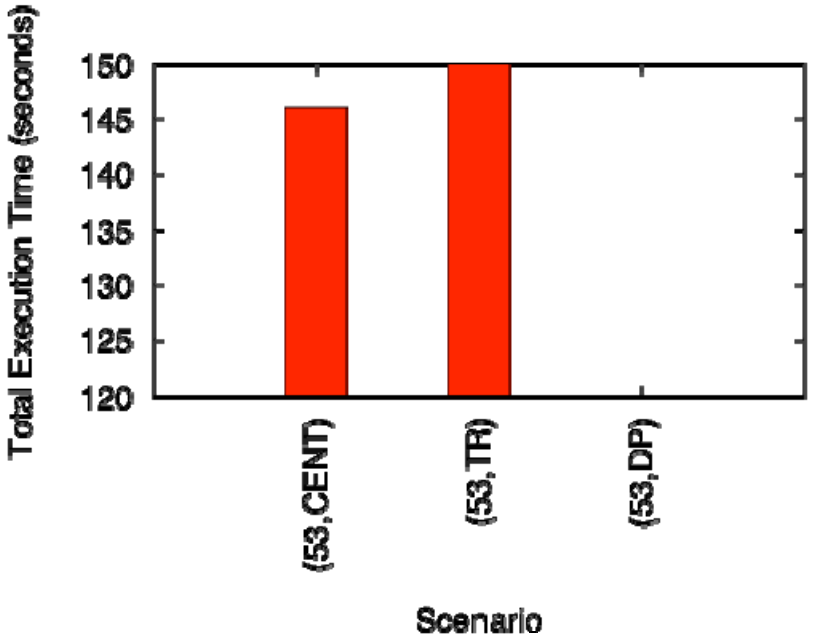
UTOPAR in BIP

- Fully automated generation of distributed C++ code, using sockets

25 = 5 * 5 calling units and 4 cars –
29 Interaction Protocols



49 = 7 * 7 calling units and 4 cars –
53 Interaction Protocols



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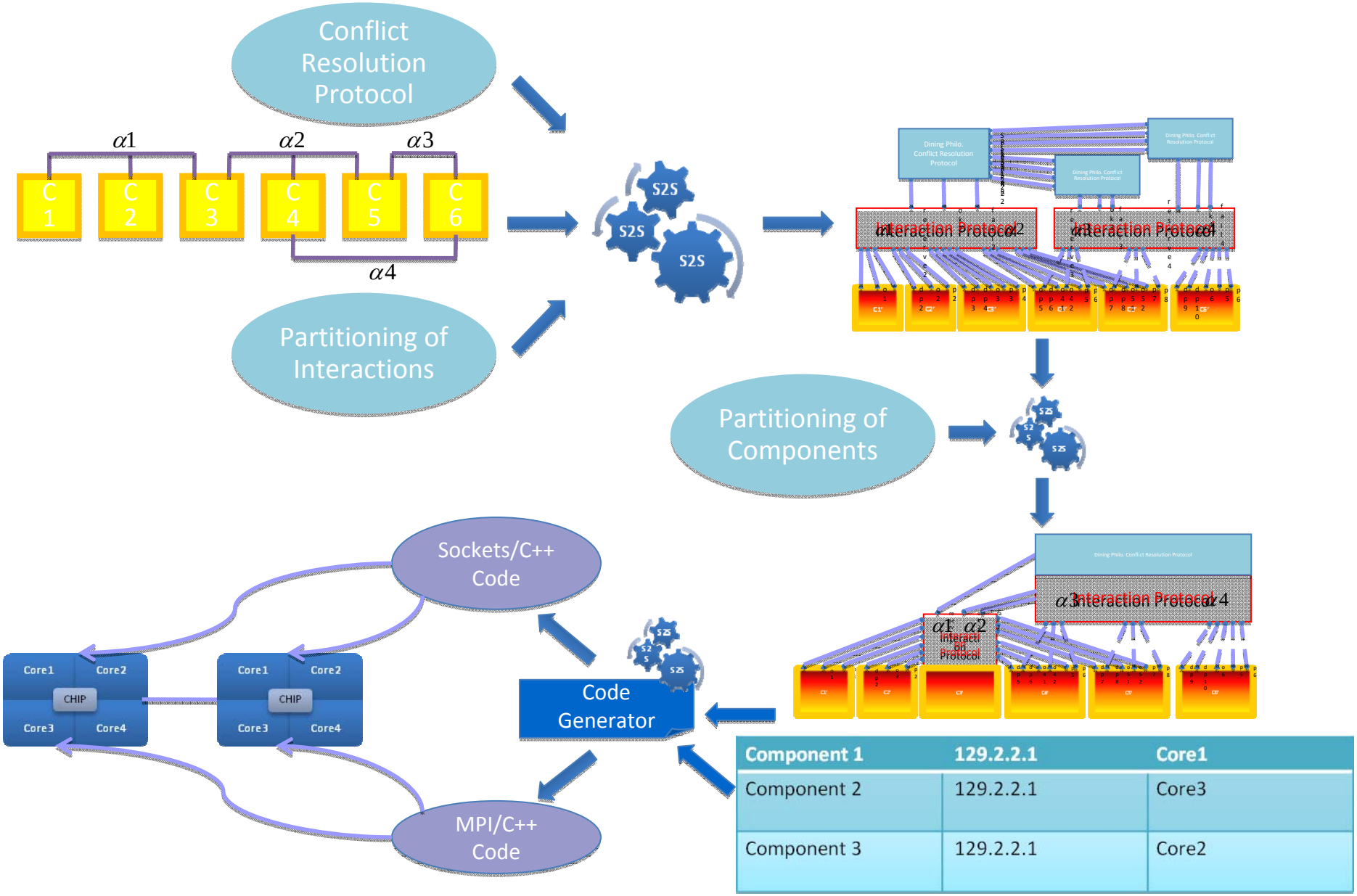
Discussion - Detailed Design Flow

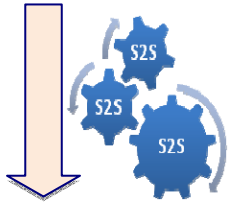


Component 1	129.2.2.1	Core1
Component 2	129.2.2.1	Core3
Component 3	129.2.2.1	Core2

Discussion

Single Engine: Execution of Interactions + Conflict Resolution

Interaction Partitioning

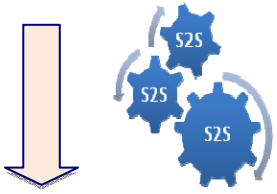


Multiple Engines: Interaction Protocol + Conflict Resolution Protocol

Tradeoff: Degree of parallelism vs. Overhead for coordination depending on

- Interaction partitioning
- Conflict resolution protocol (Centralized, Token Ring, Dining Philosophers etc.)

Component Partitioning



Implementation: maximal parallelism, load balancing, resource management

Discussion – Ongoing Work

- Distributed model with priorities – an additional layer is needed
- Application for automated implementation on many-core platforms
- Global analysis techniques jointly taking into account
  - interaction partitioning
  - component partitioning
  - HW resources
- Performance evaluation and design space exploration tools
- Case studies

Thank You