Correct-by-construction Distributed Implementations for BIP

WFCD 09

Grenoble, October 11, 2009

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in collaboration with

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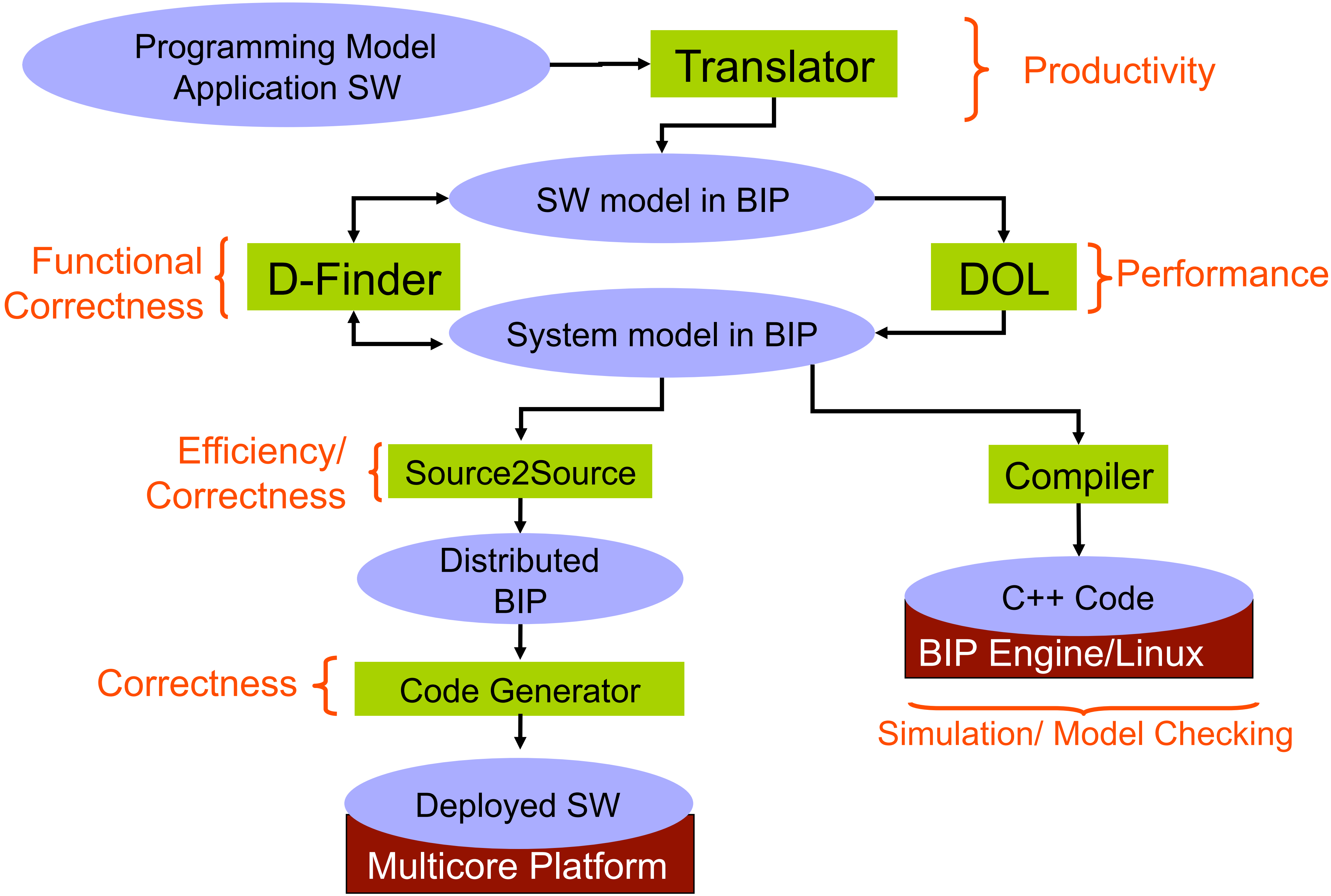
System Design Flow



System Design Flow – Methodology

- Use BIP as a unifying semantic model for the various programming models e.g. synchronous, data flow, event driven

- Constructivity results - rules for inferring global properties from properties of constituent components

- Generate from a model of the application software and a model of the target platform, an implementation by using a set of correct-by-construction model transformations
  - preserving functional properties
  - taking into account extra-functional requirements

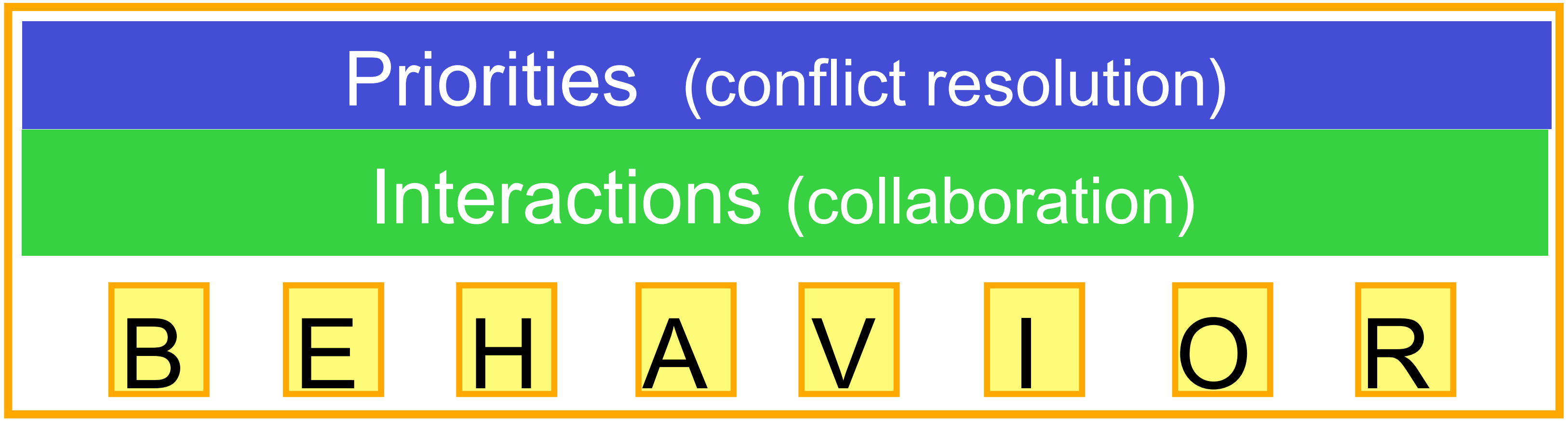
  Types of transformations studied:
  - From BIP to distributed BIP (BIP using asynchronous message passing only)
  - Architecture transformations
  - From BIP (message passing) models to shared memory models e.g. shared/private memory transformations
  - Integrating architecture constraints, e.g. HW/SW partitioning and mapping

OVERVIEW

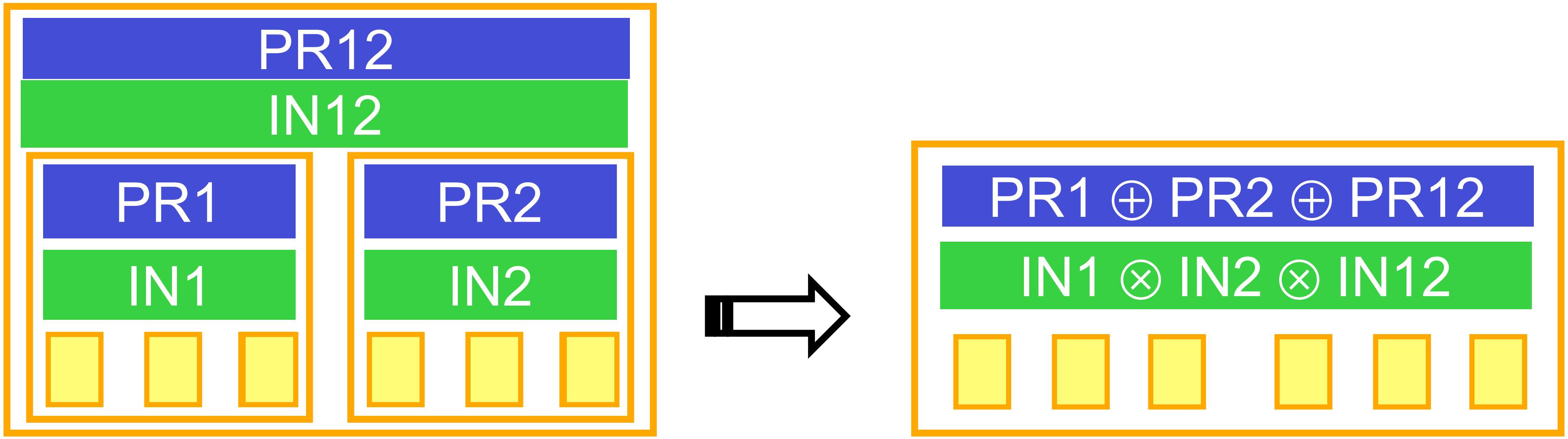
- BIP – Global state model
- Distributed centralized implementation
- Decentralized implementations
- Architecture transformations
- Discussion

BIP – Basic Concepts

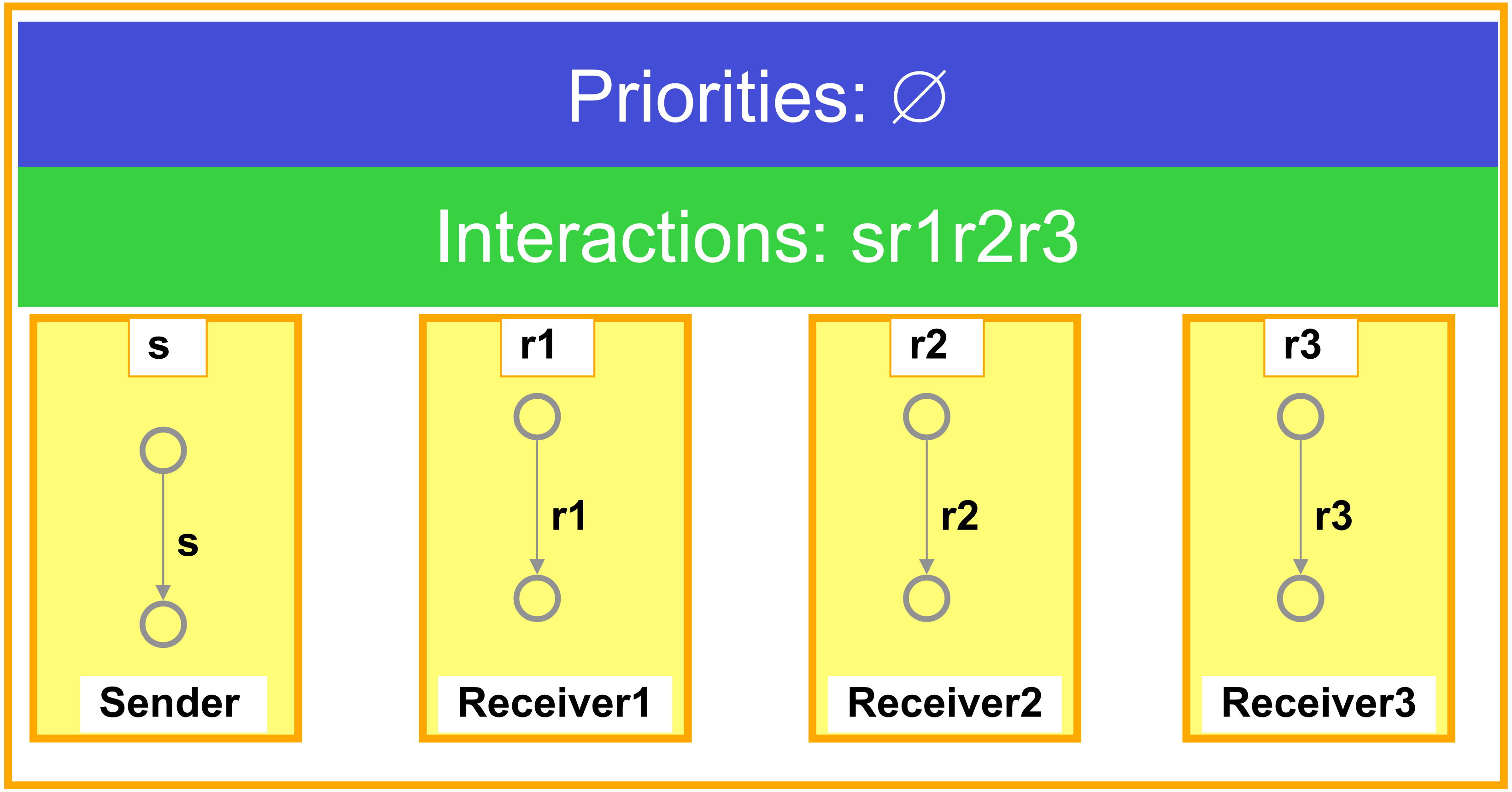
Layered component model



Composition operation parameterized by glue IN12, PR12

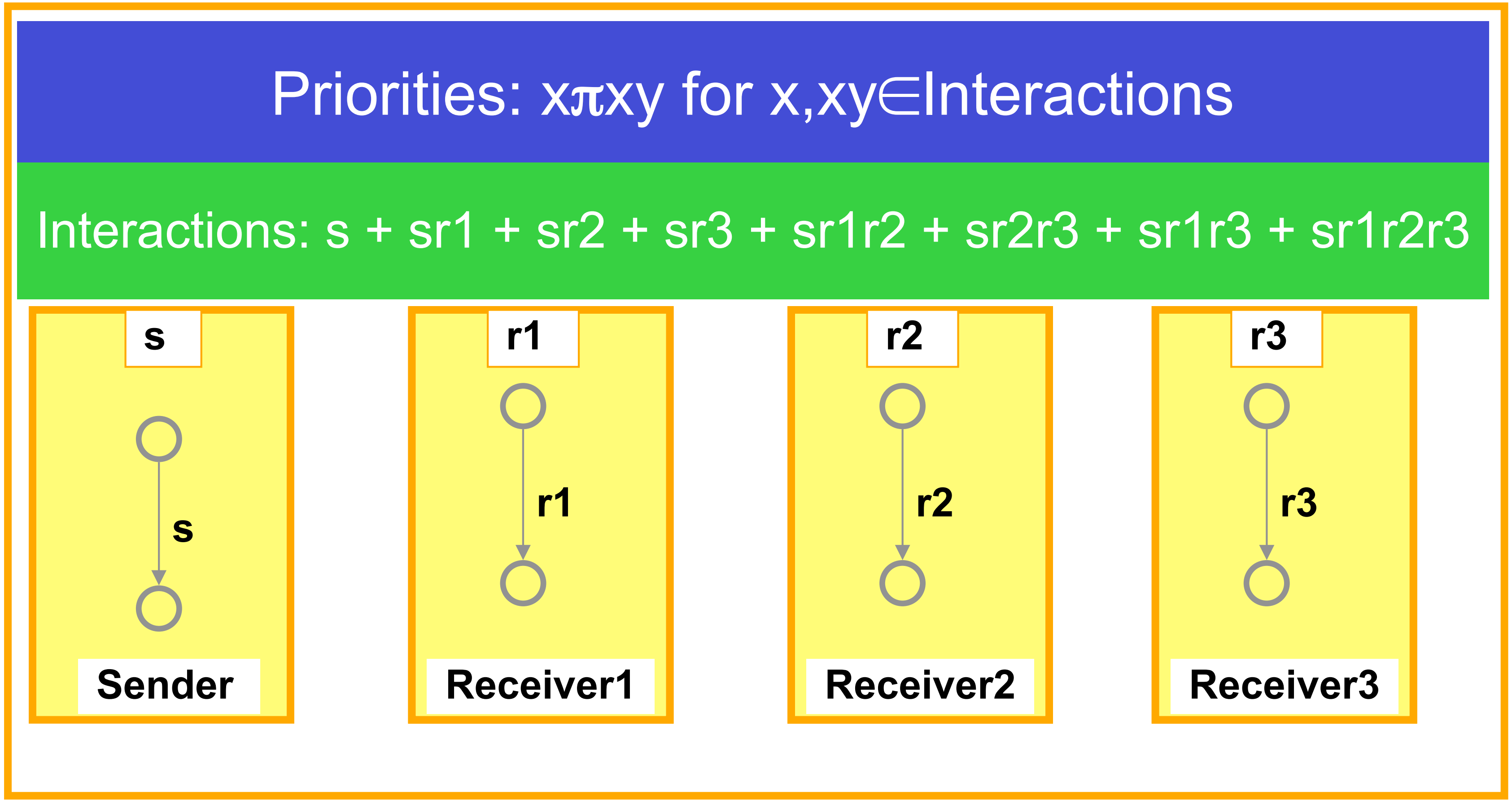


BIP – Basic Concepts



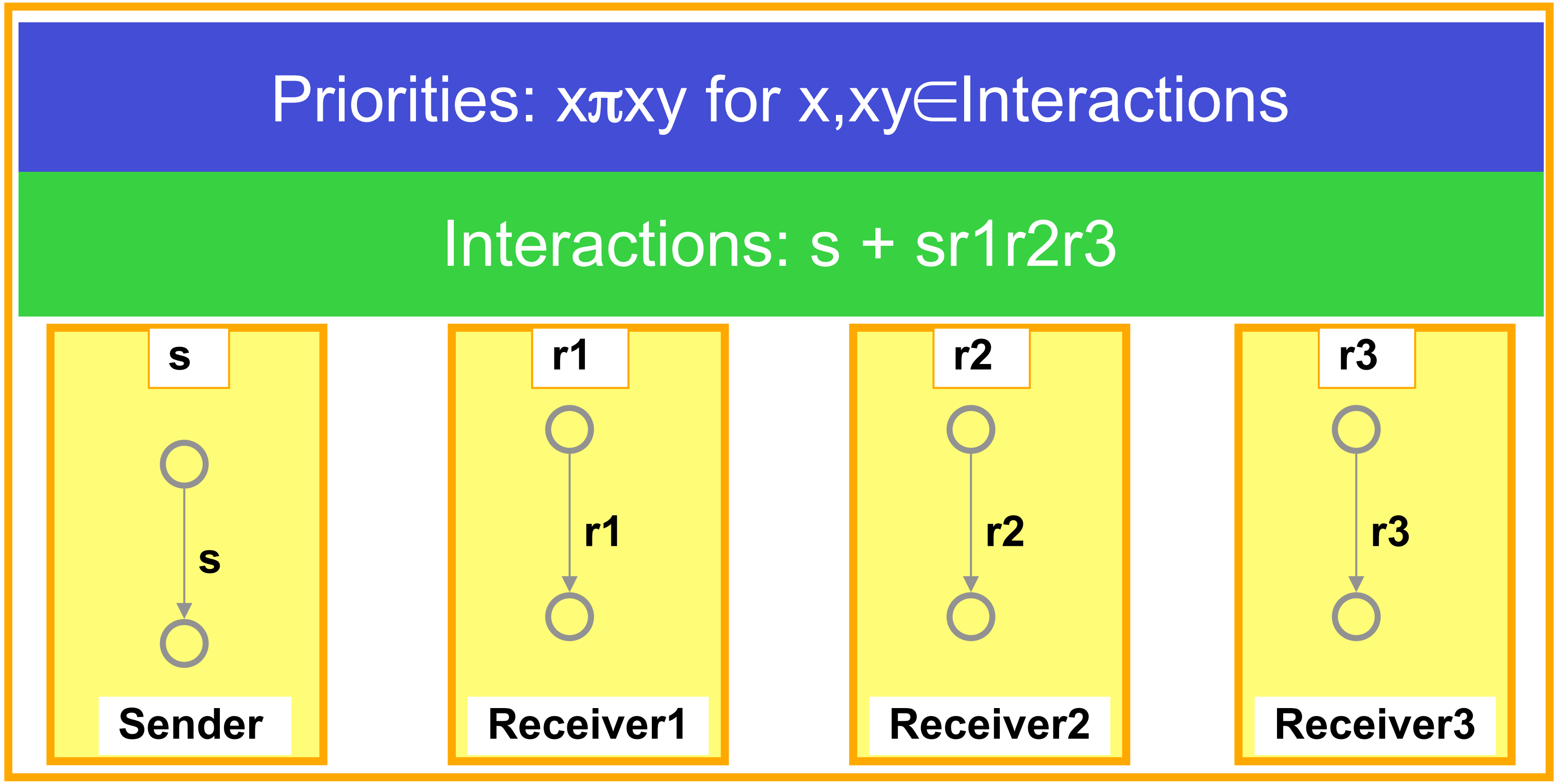
Rendezvous

BIP – Basic Concepts

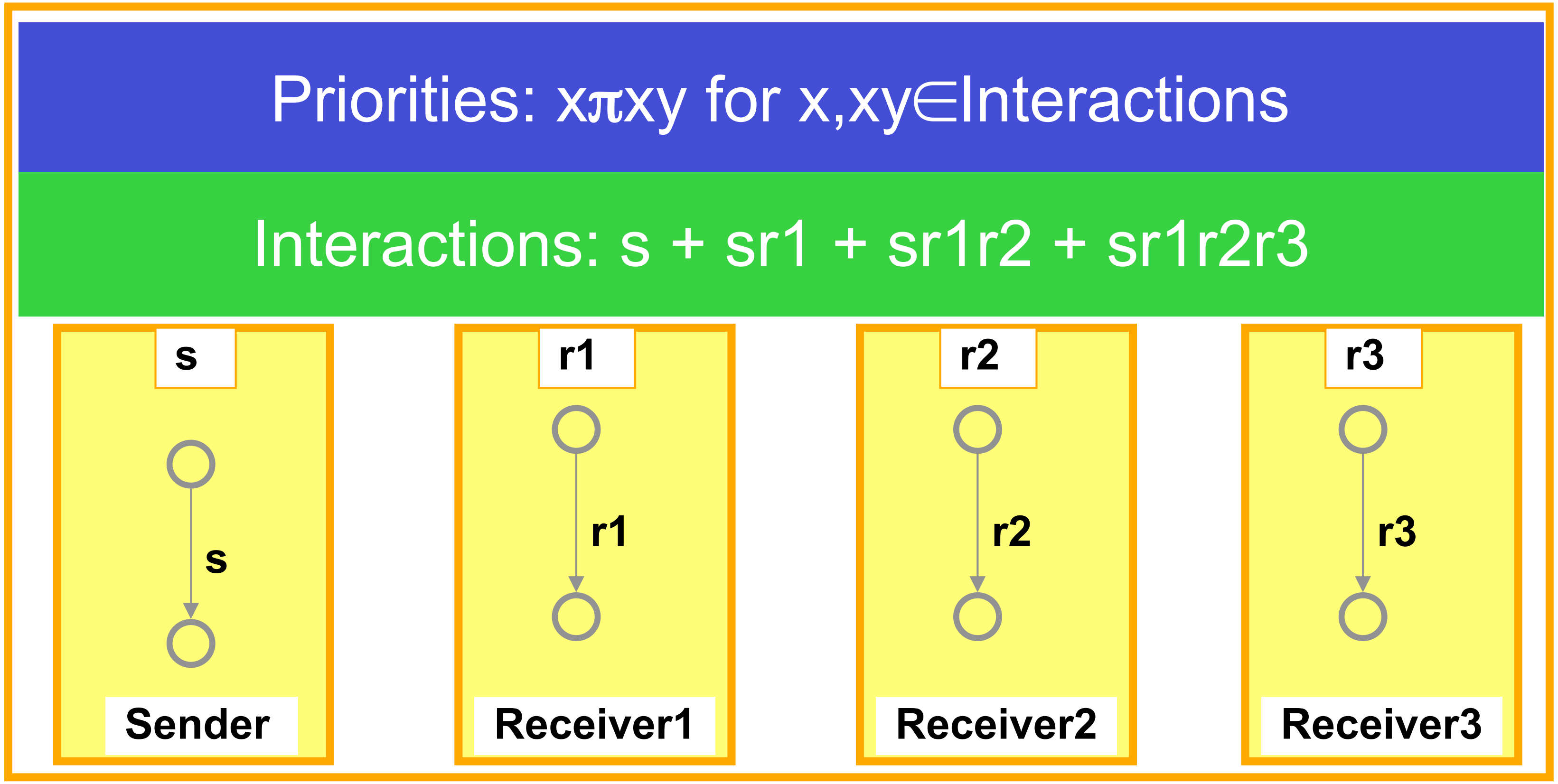


Broadcast

BIP – Basic Concepts



Atomic Broadcast



Causal Chain

BIP – Basic Concepts: Semantics

$$\left.\begin{array}{l}\text{▪ a set of atomic components } \{B_i\}_{i=1..n} \\ \quad \text{where } B_i = (Q_i,\ 2^{P_i},\ \rightarrow_i) \\ \text{▪ a set of interactions } \gamma \\ \text{▪ priorities } \pi \subseteq \gamma \times (\otimes Q_i) \times \gamma\end{array}\right\} \pi\,\gamma\,(B_1,.., B_n)$$

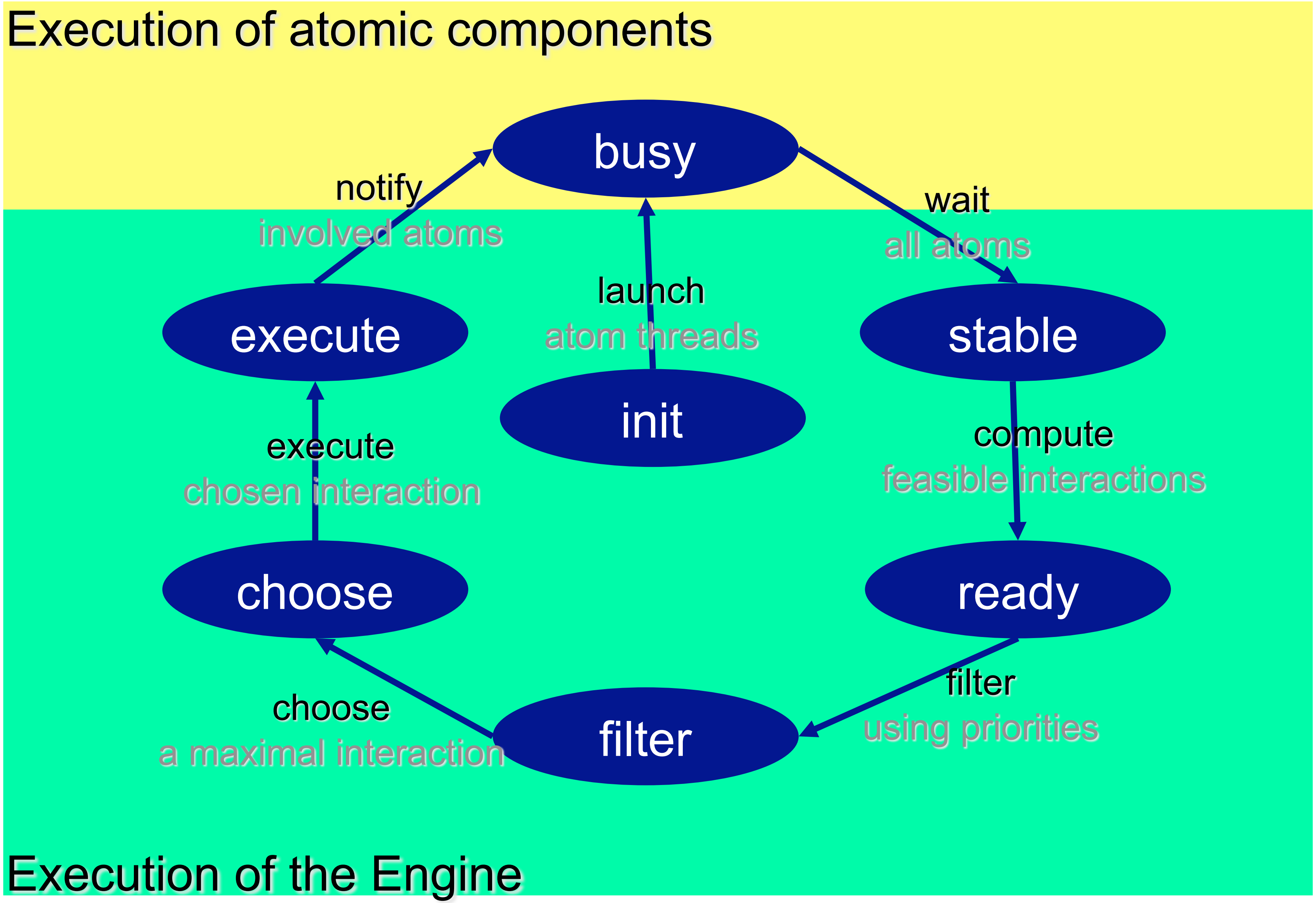
Interactions

$$\frac{a \in \gamma \qquad \forall i \in [1,n]\ \ q_i \text{ - } a \cap P_i \rightarrow_i q'_i}{(q_1 ,.., q_n) \text{ - } a \rightarrow_\gamma (q'_1 ,.., q'_n) \ \text{ where } q'_l = q_l \text{ if } a \cap P_i = \varnothing}$$

Priorities

$$\frac{q\text{- } a \rightarrow_\gamma q' \quad \neg\ (\exists\, q\text{- } b \rightarrow_\gamma \ \wedge\ a\ \pi_q\ b\,)}{q\text{- } a \rightarrow_\pi q'}$$

BIP – The execution Engine



OVERVIEW

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Distributed Implementation

BIP is based on:

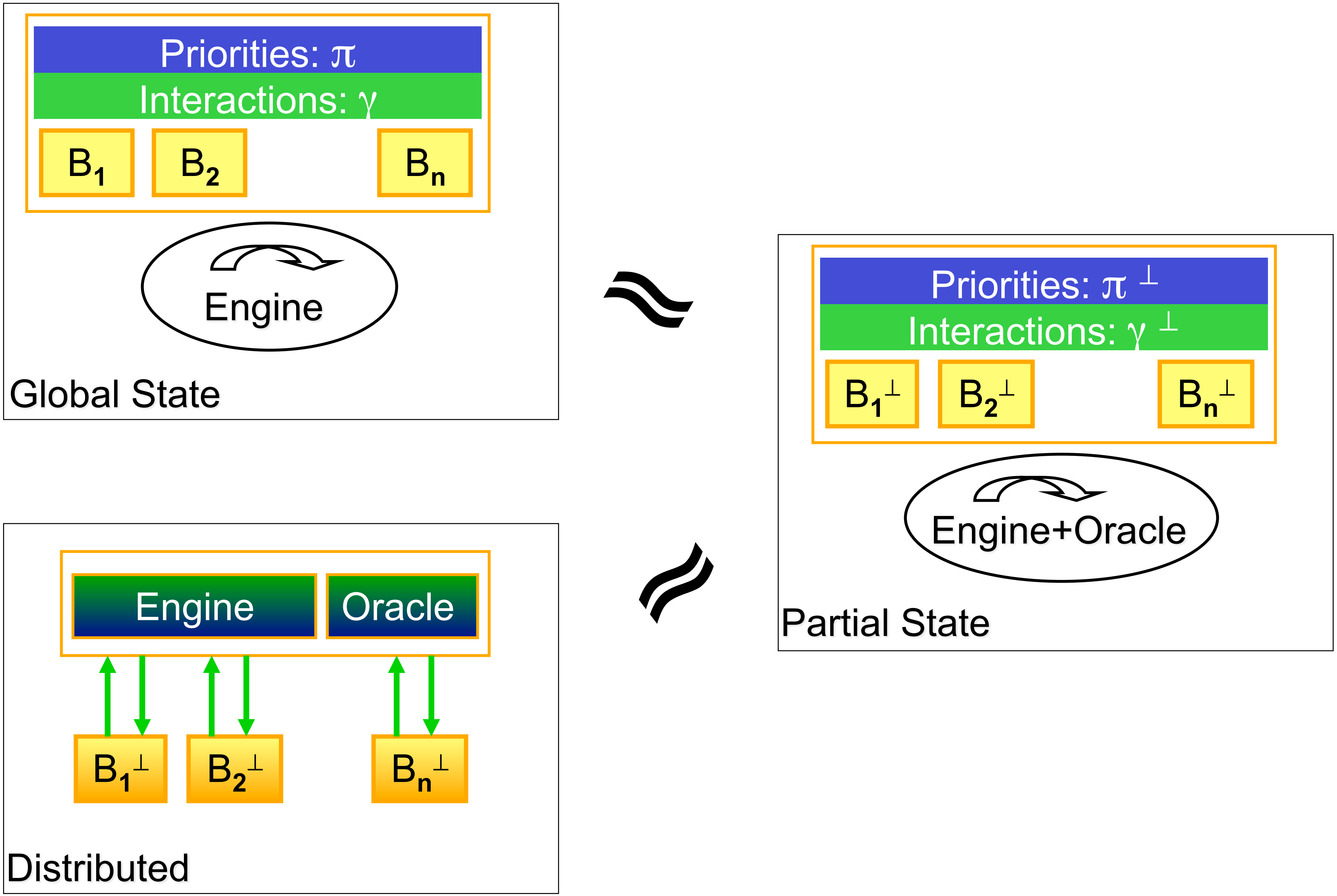
- ❑ Global state semantics, defined by operational semantics rules, implemented by the Engine
- ❑ Atomic multiparty interactions, e.g. by rendezvous or broadcast

Translate BIP models into distributed models

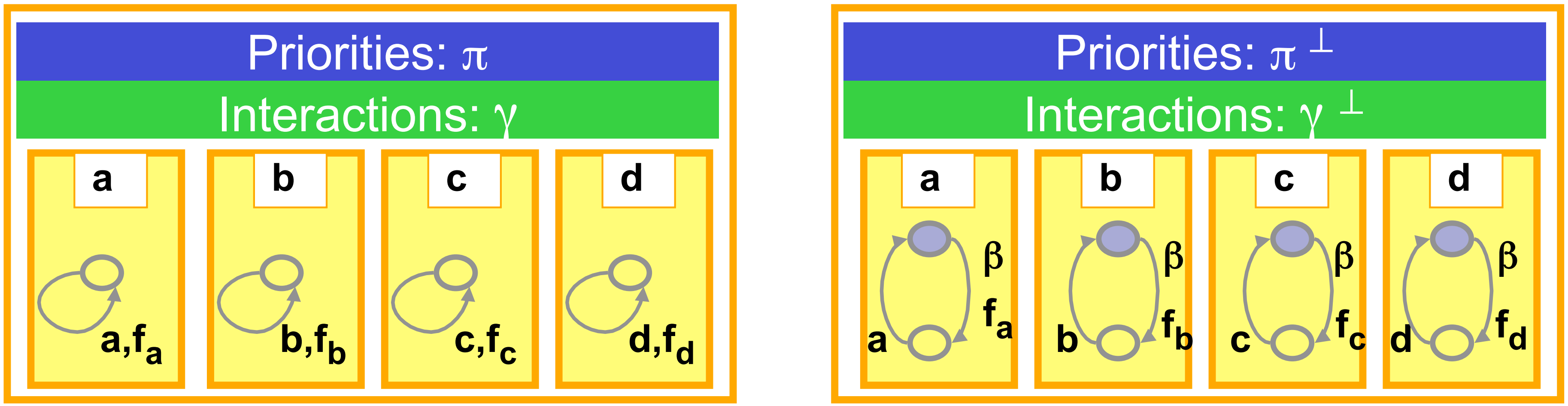
- ❑ Collection of independent components intrinsically concurrent - No global state
- ❑ Separate interaction from internal computation of components
- ❑ Point to point communication by asynchronous message passing
- ❑ Correctness by construction that is, the initial BIP model is observationally equivalent to the implementation

Approach: BIP $\Rightarrow$ Partial state BIP $\Rightarrow$ Distributed BIP

Centralized Distributed Implementation – The Principle



Distributed Implementation – Global vs. Partial State Models



(a) Global State Model

(b) Partial State Model

Broadcast γ = a+ab+ac+ad+abc+abd+acd+abcd, with maximal progress.

(a): only abcd is possible.

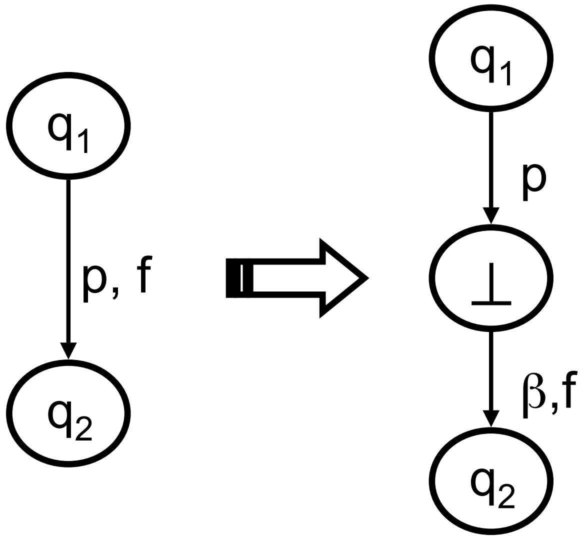
(b): arbitrary desynchronization may occur.

Rendezvous γ = ab+bc+cd and priority abπbc, cdπbc .

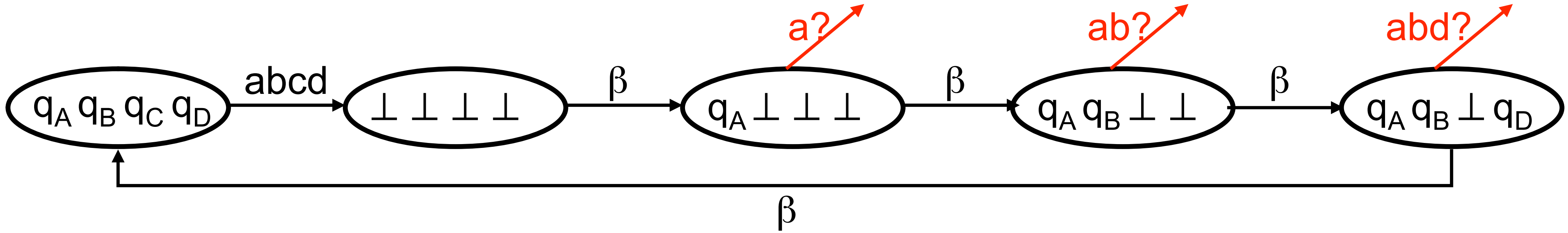
(a): only $(bc)^\omega$ is possible

(b): it is possible to reach a state from which bc never occurs e.g. ab(f_a cd f_b f_d ab f_c)$^\omega$.

Distributed Implementation – Partial state semantics



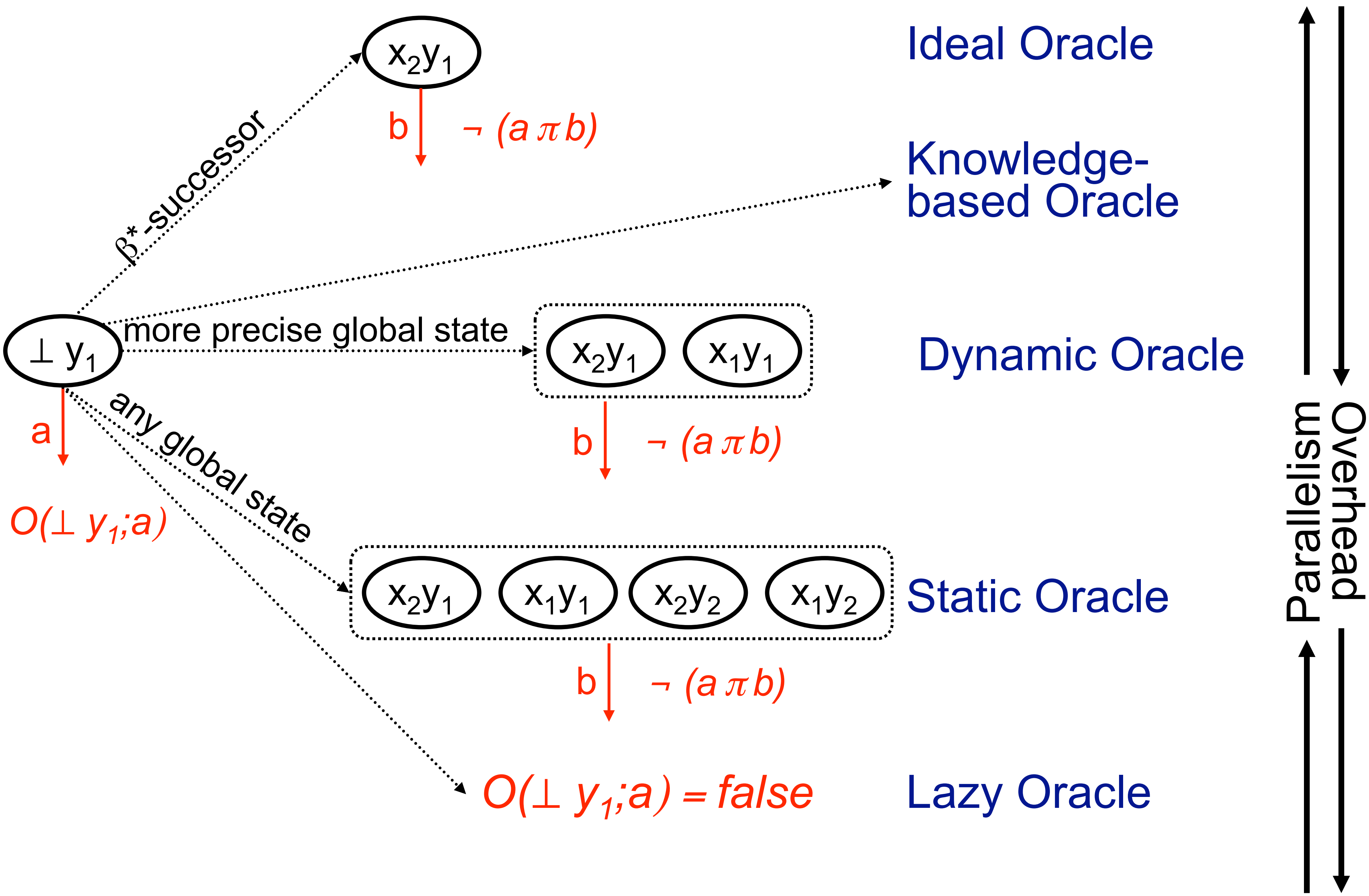
- States are global or partial
- β-transitions interleave
- From any state q a unique global state is reached by application of β-transitions



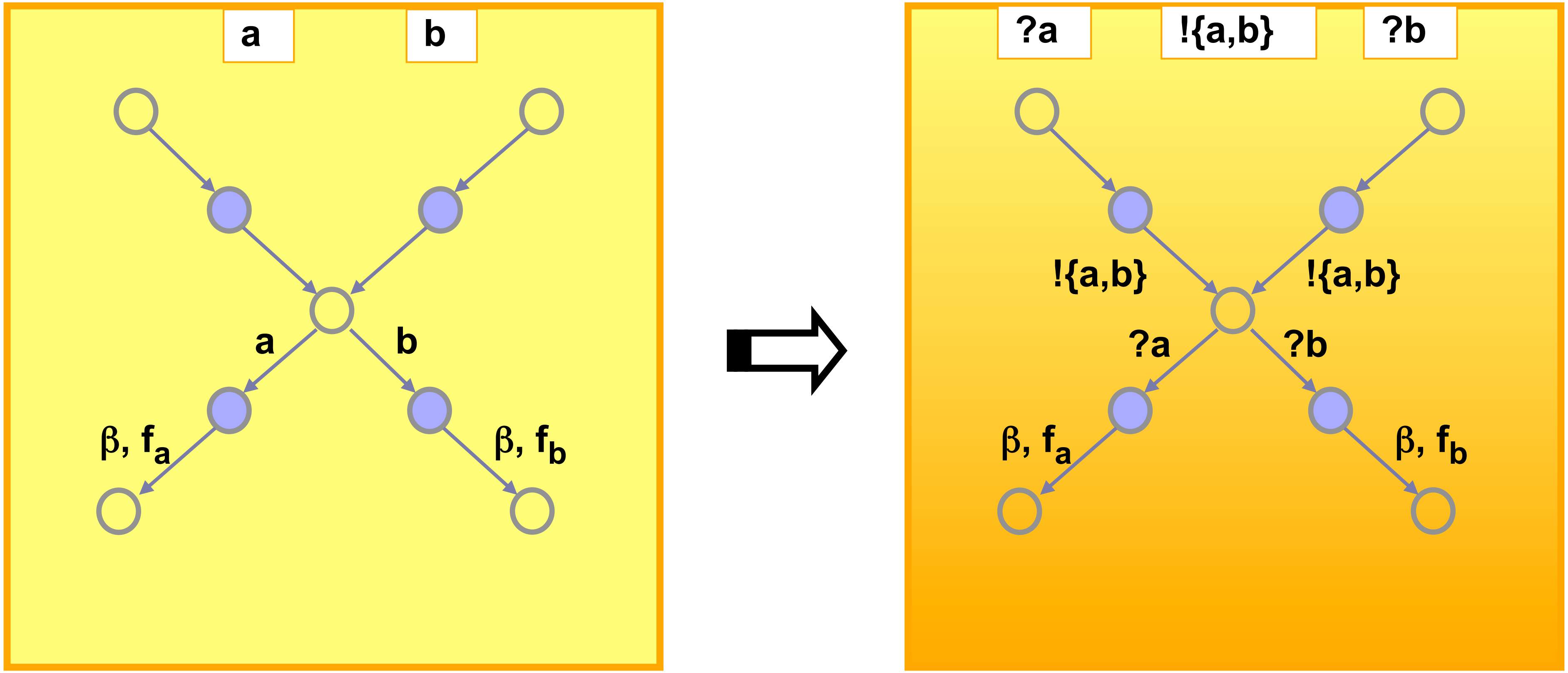
Objective: Safe and efficient execution from partial states

$$\frac{a\in\gamma \qquad \forall i\in[1,n]\ \ q_i \xrightarrow{a\cap P_i}_i q'_i \qquad O(q_1,..,q_n;a)}{(q_1,..,q_n) \xrightarrow{a}_\gamma (q'_1,..,q'_n)\ \ \text{where } q'_i=q_i \text{ if } a\cap P_i=\emptyset}$$

Distributed Implementation – Oracles



Distributed Implementation – Asynchronous MP Model

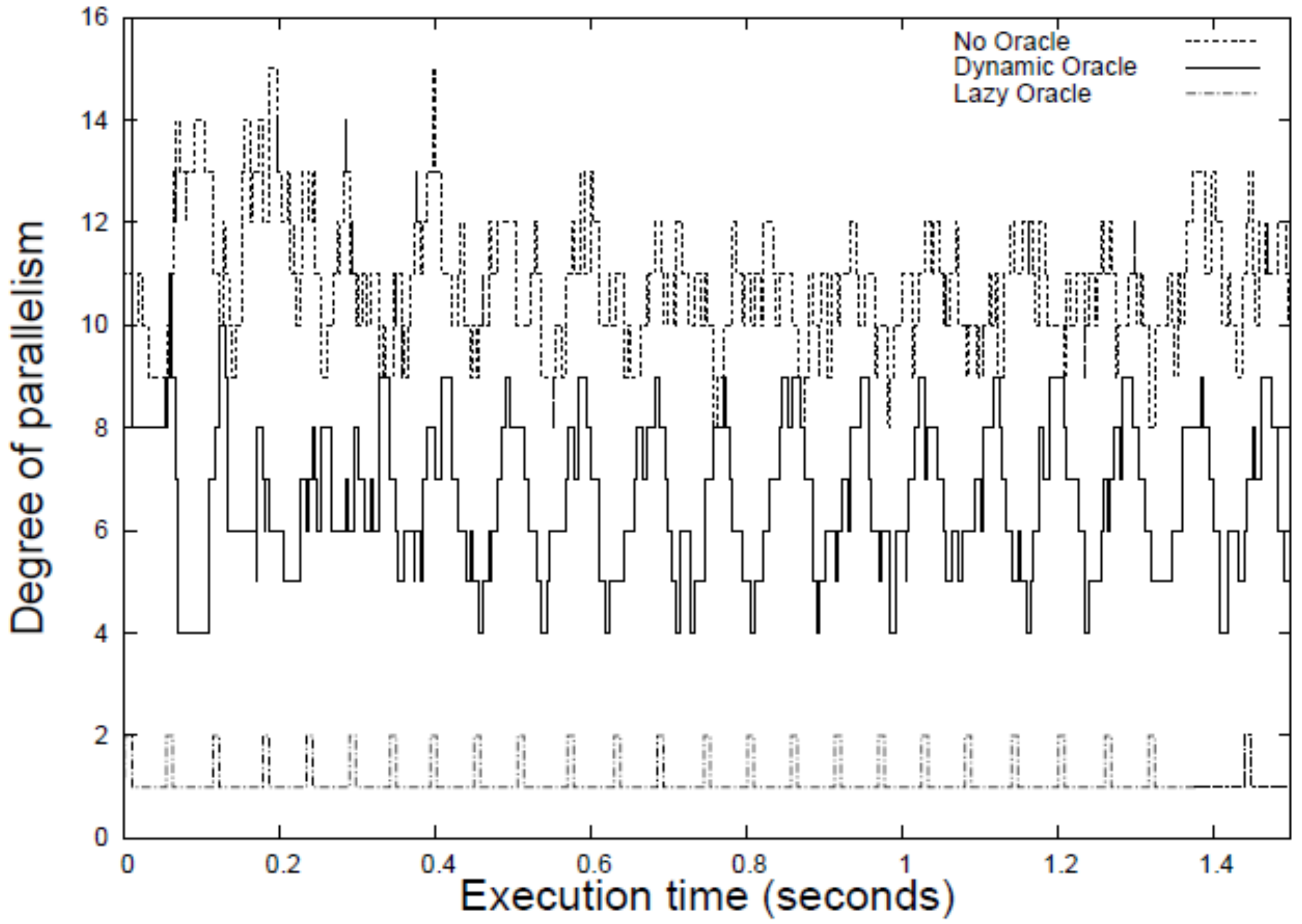


Partial State Model

Message Passing 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

Distributed Implementation – Example (Forte 08)



- No oracle: average parallelism 10, but incorrect functional behavior.
- Lazy oracle: maximal parallelism 2.
- Dynamic oracle: average parallelism 7.

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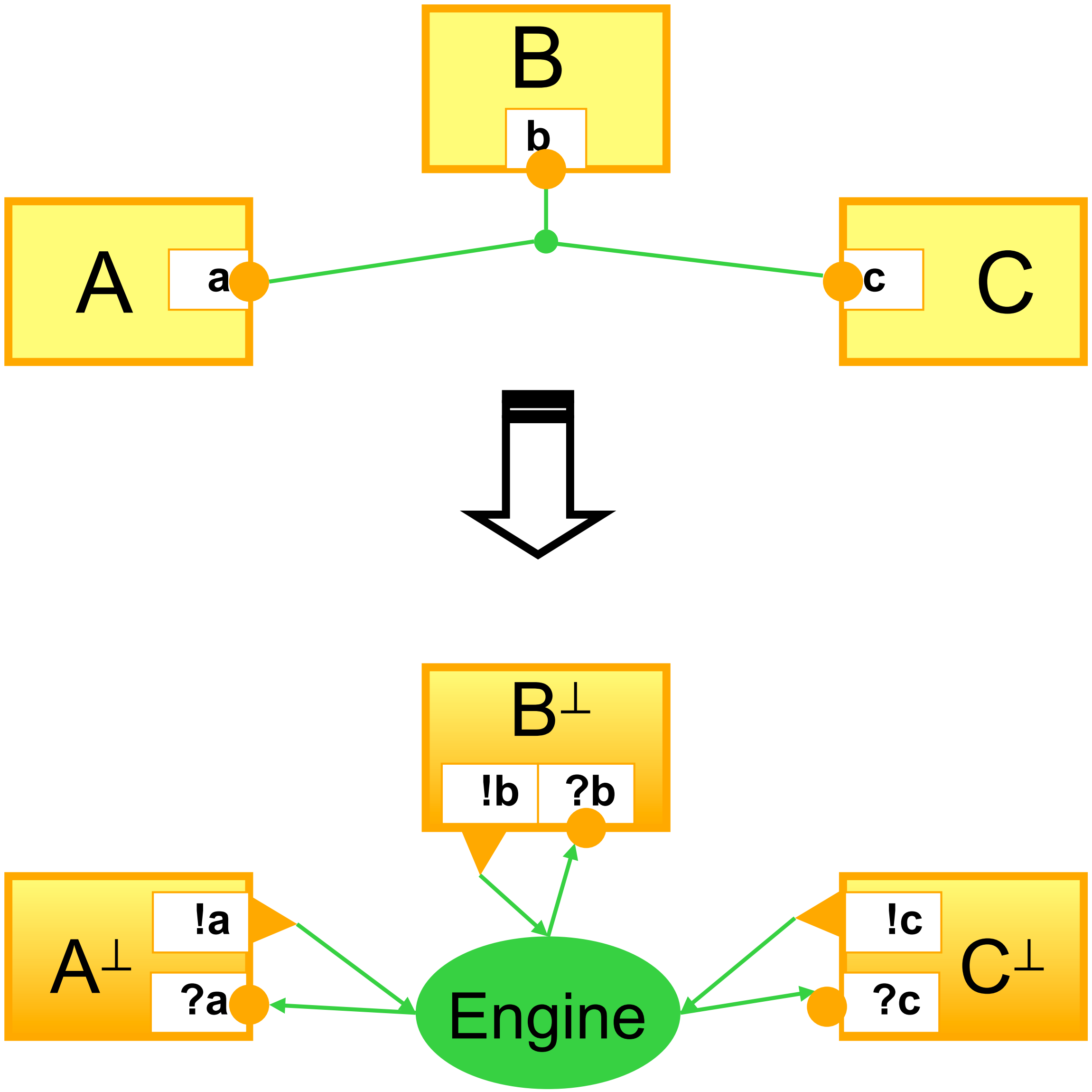
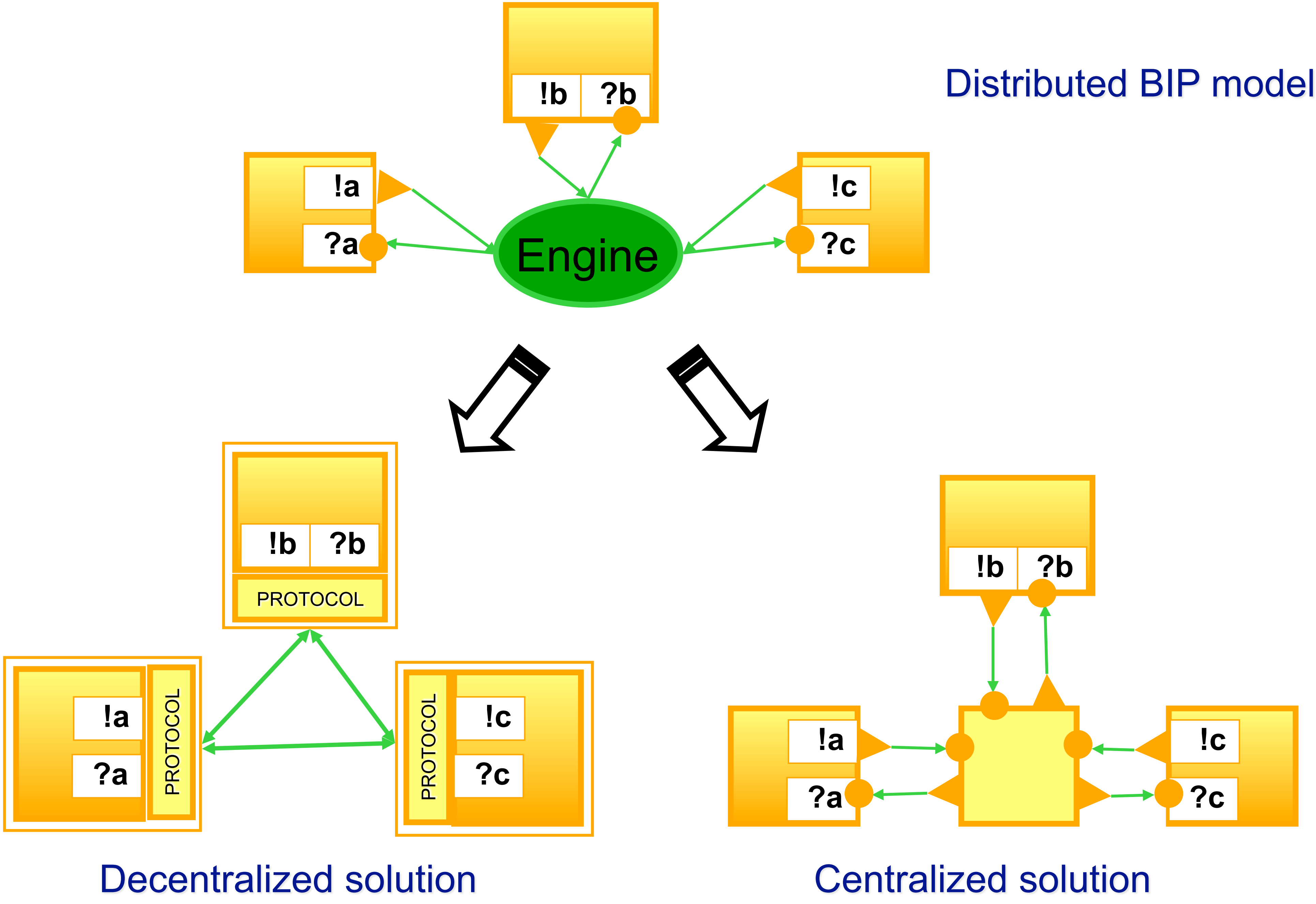
Decentralized Distributed Implementation – The principle



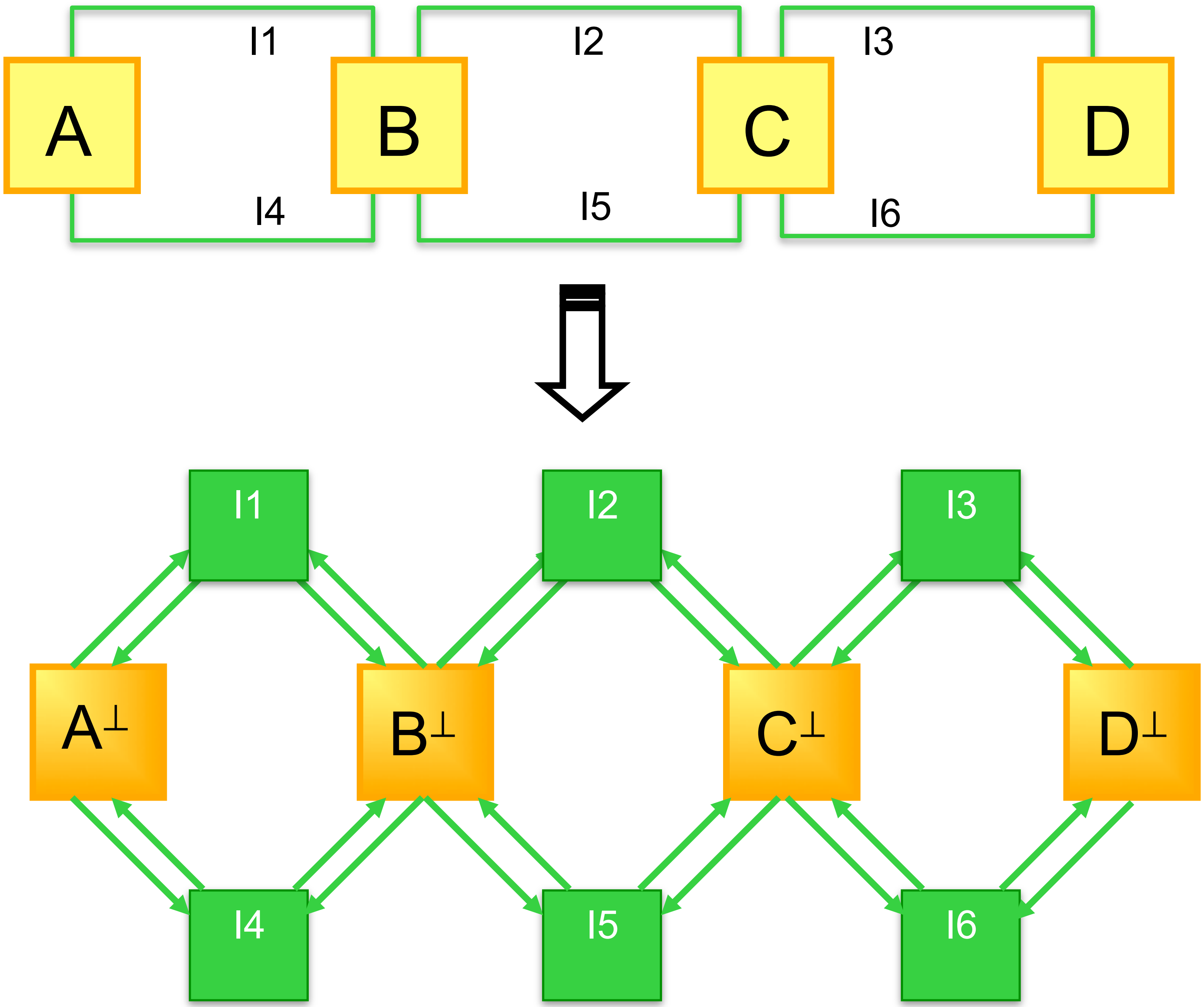
Initial BIP model

Distributed BIP model

Distributed Implementation – Implementing Connectors



Centralized solution – Conflict Resolution



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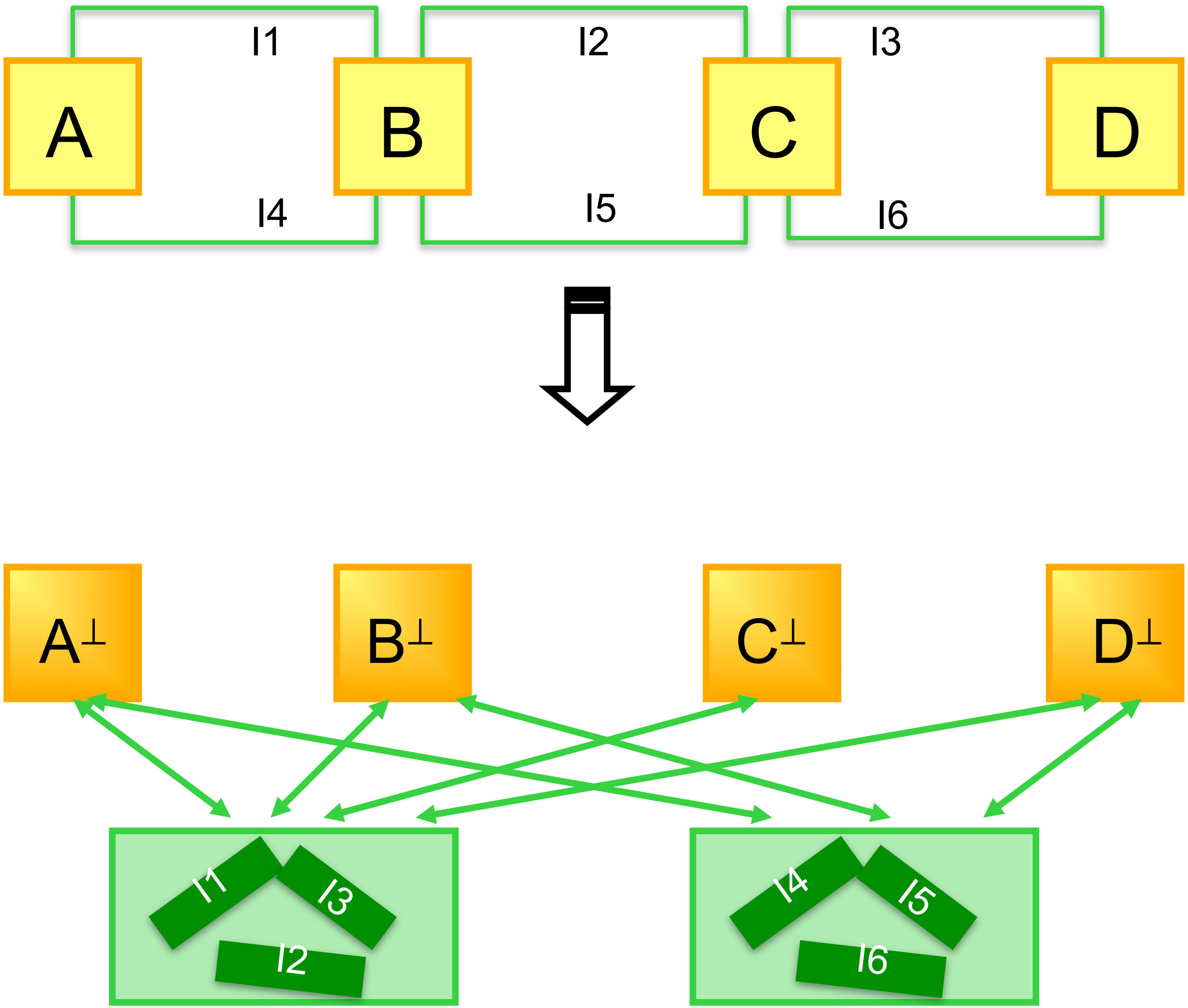

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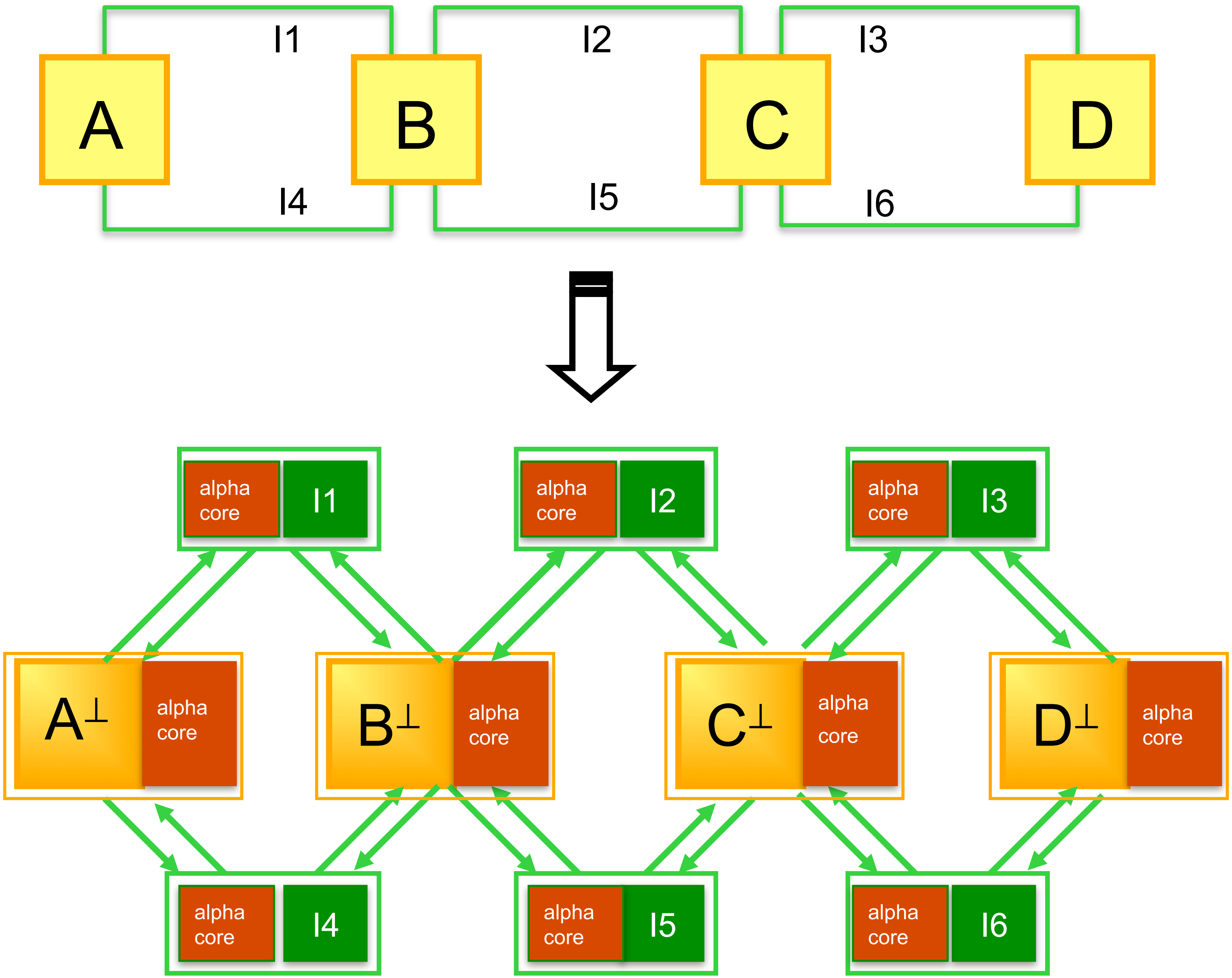

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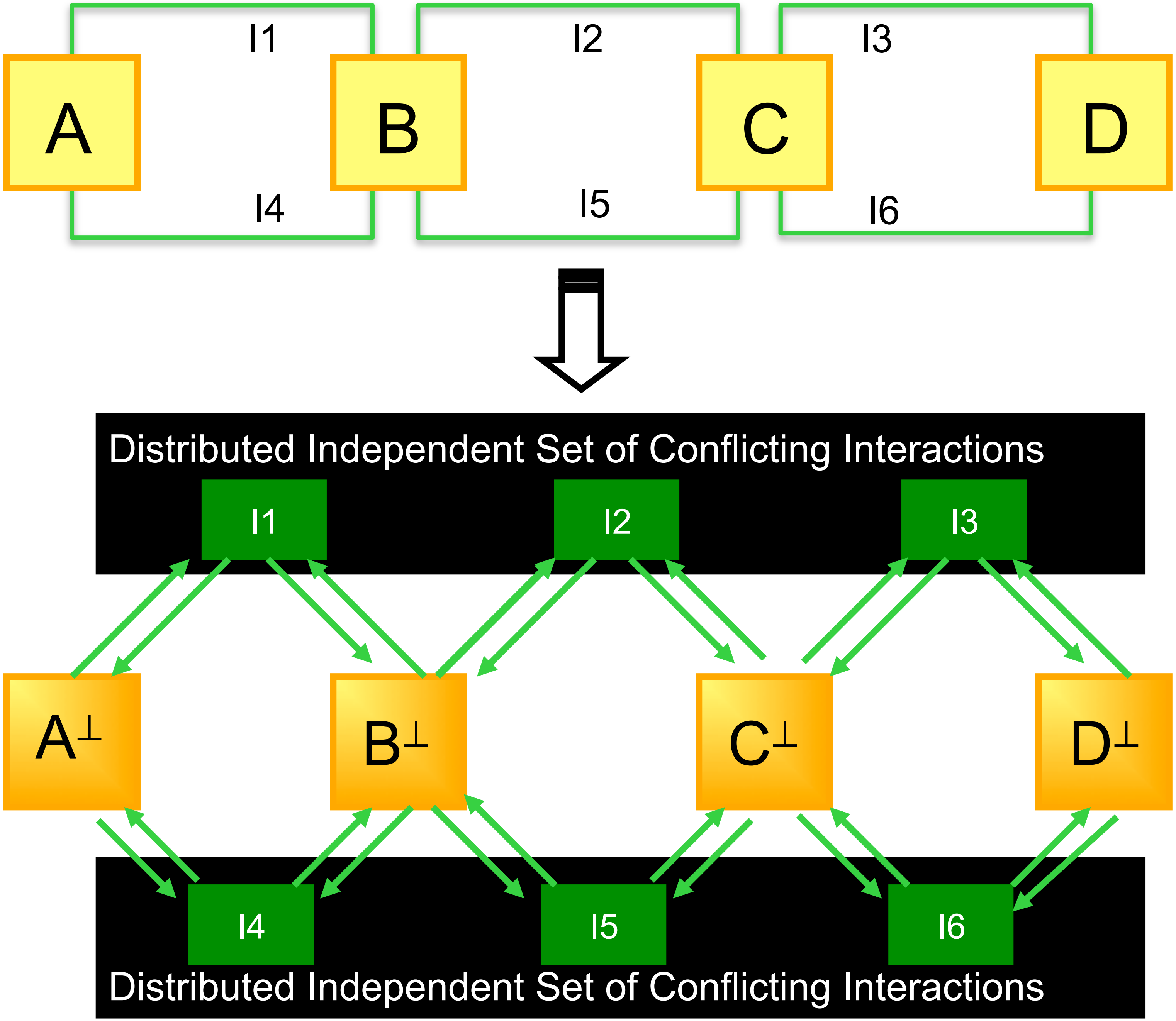

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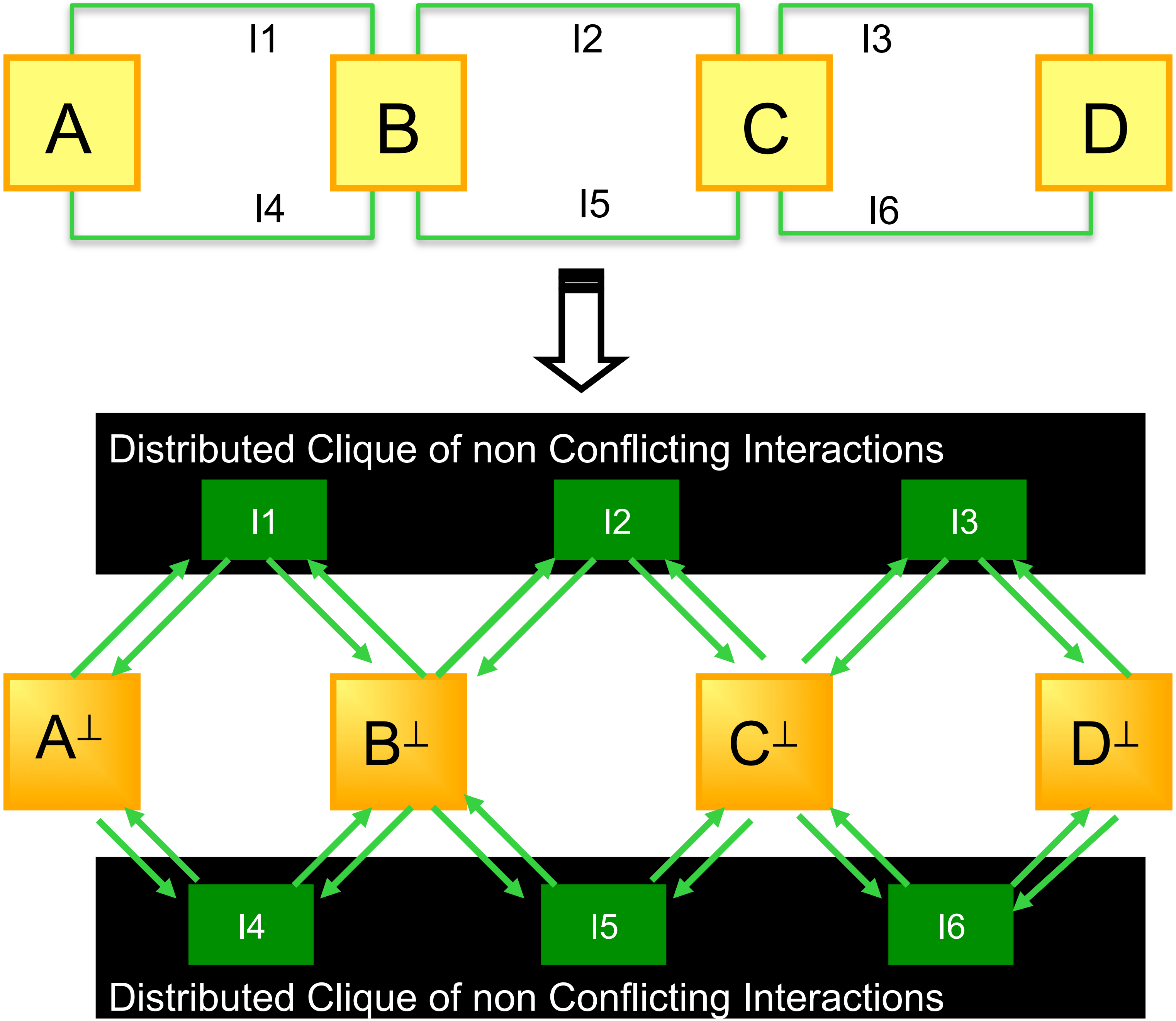
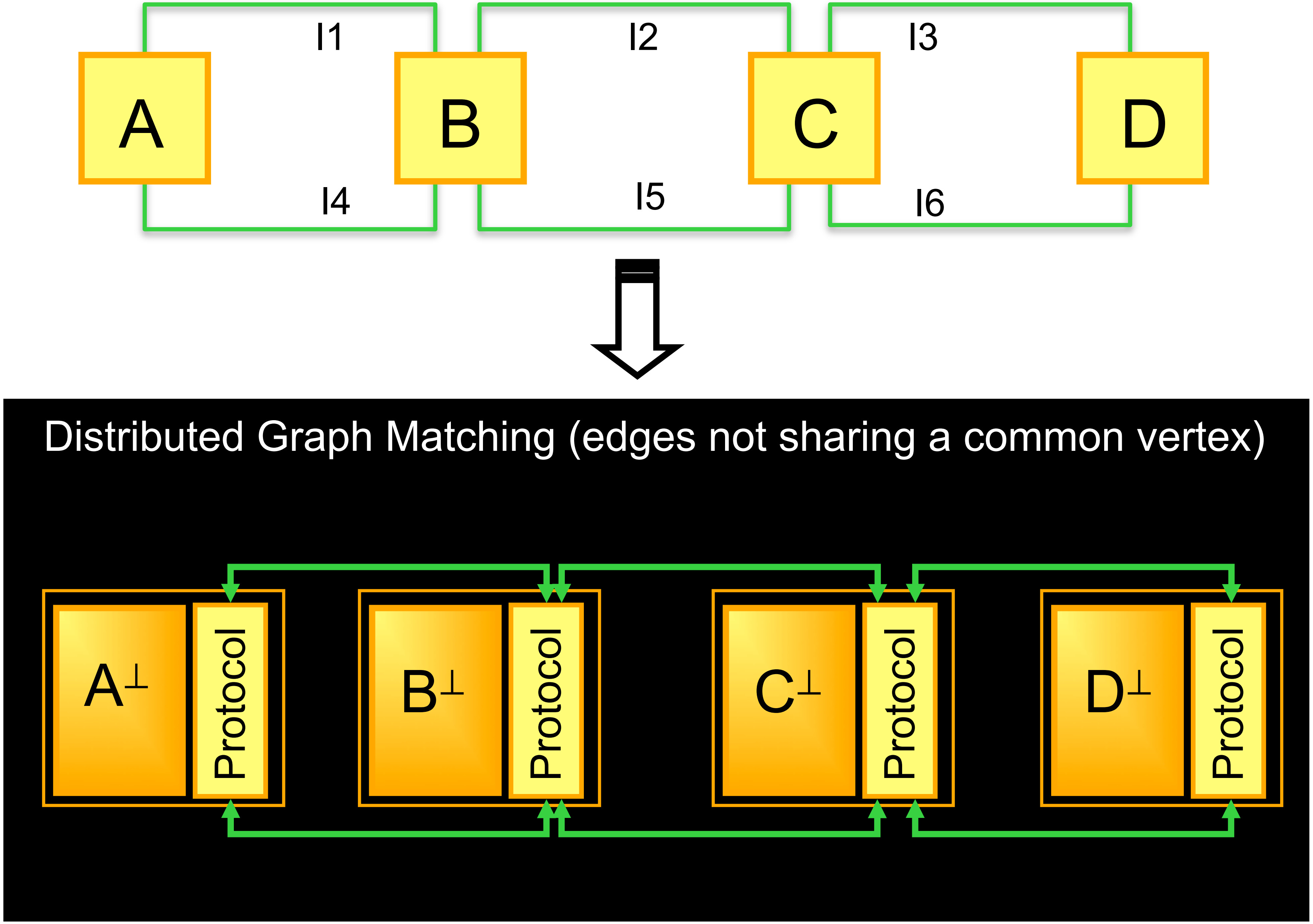


Decentralized Solution



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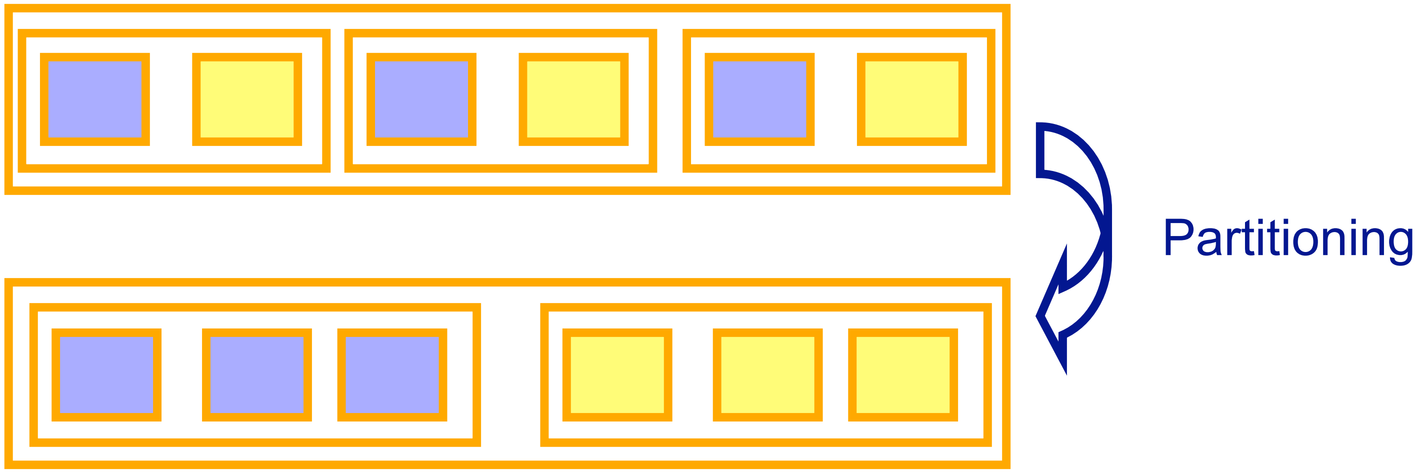
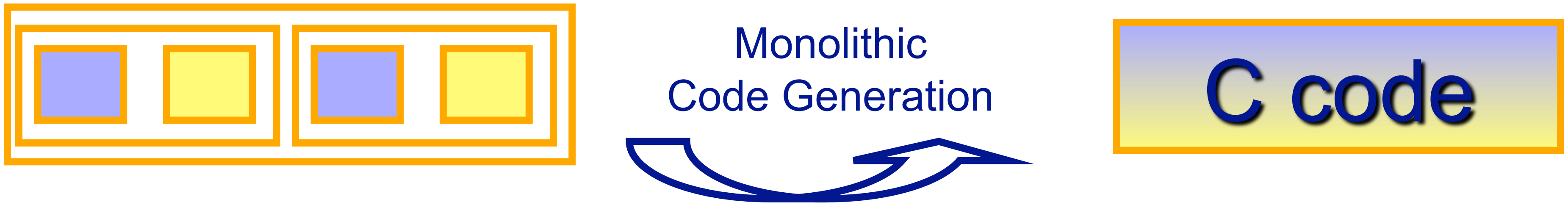
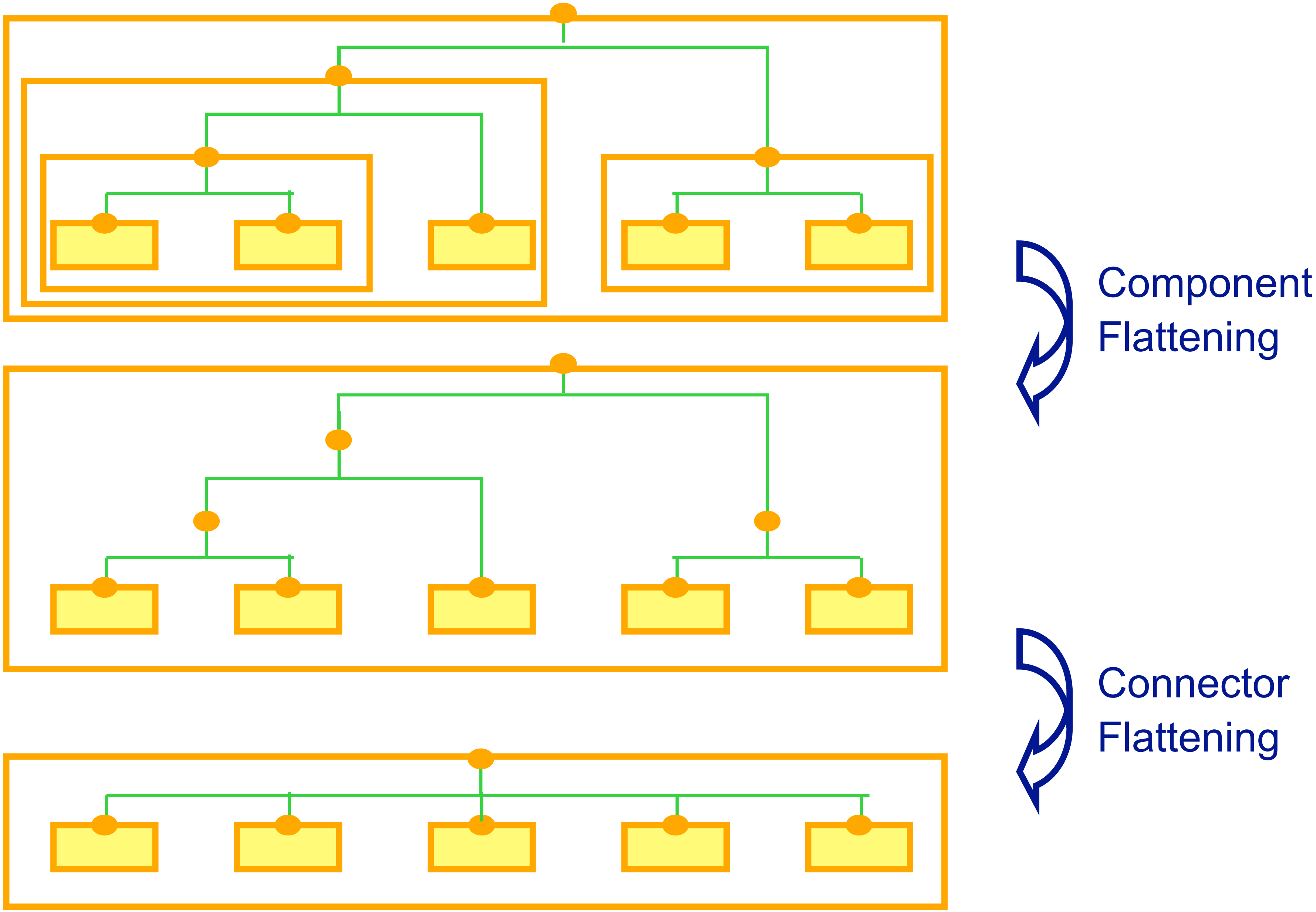
Architecture Transformations

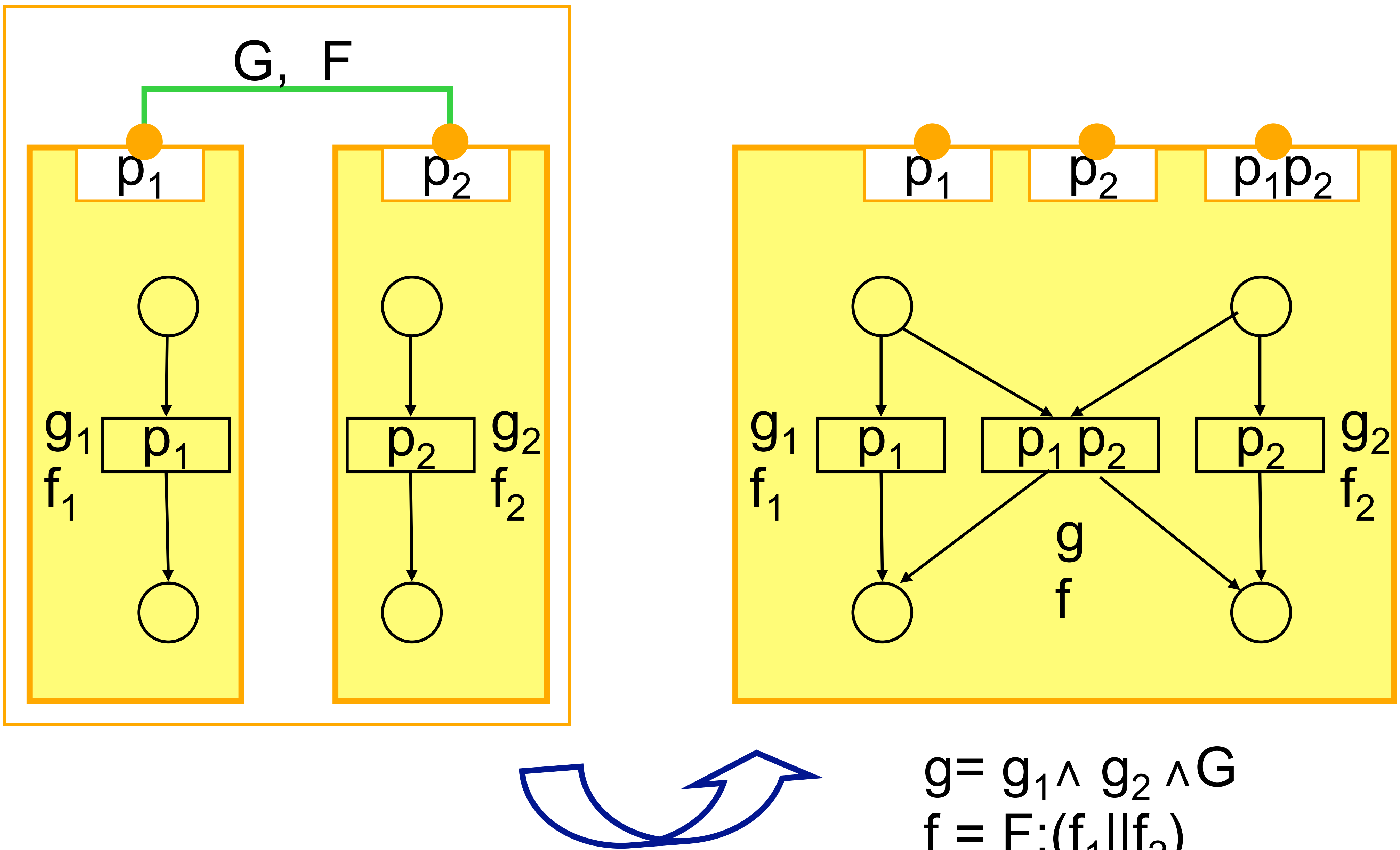




Architecture Transformations – Composite to Monolithic



Architecture Transformations – Composite to Monolithic



$g = g_1 \wedge g_2 \wedge G$

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

Example – MPEG4 Video Encoder

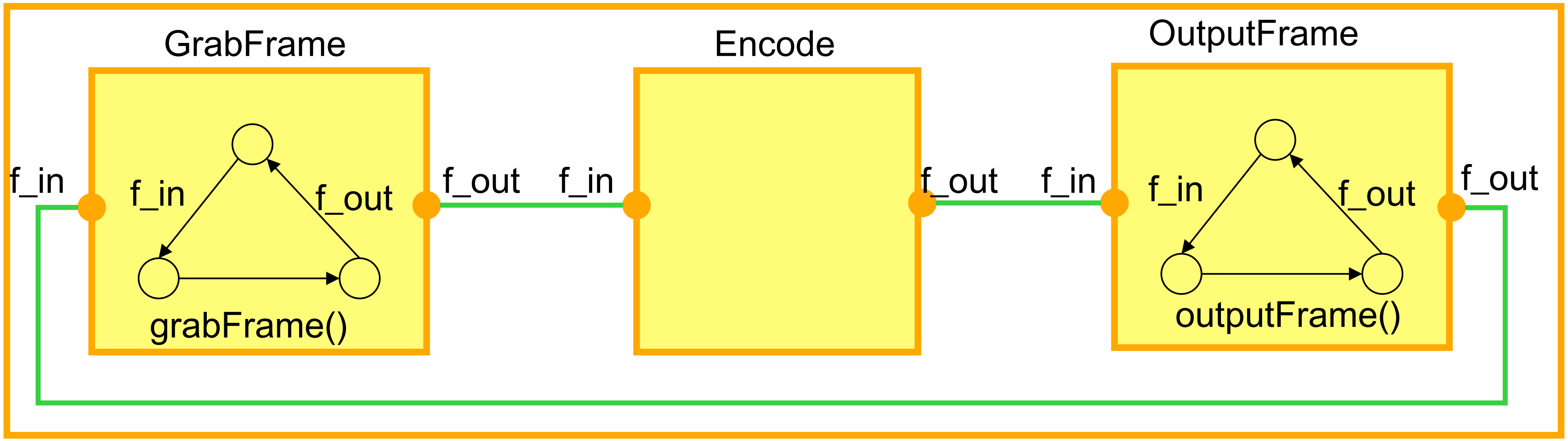
Transform the monolithic sequential program (12000 lines of C code) into a componentized one:

++ 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



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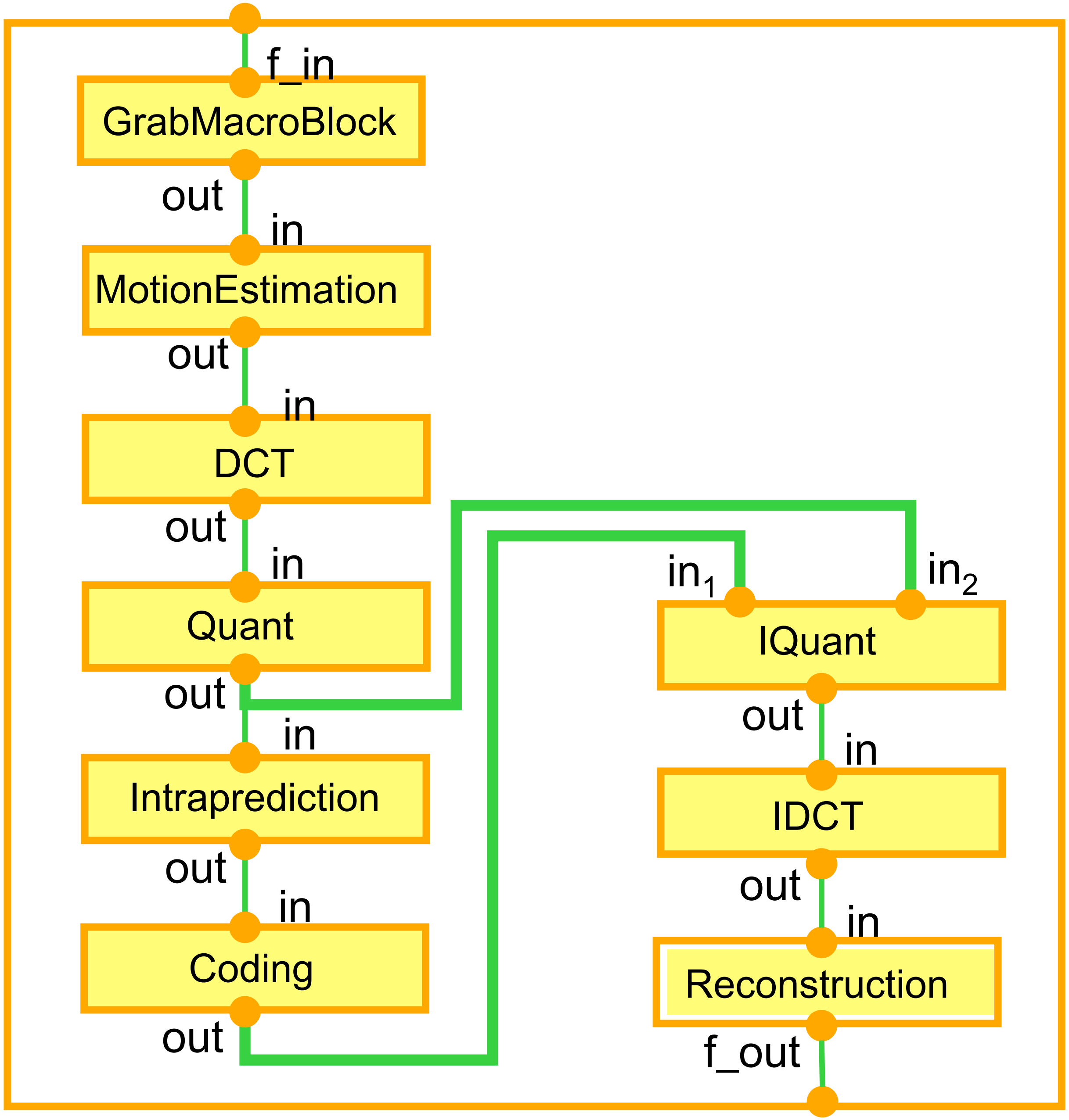
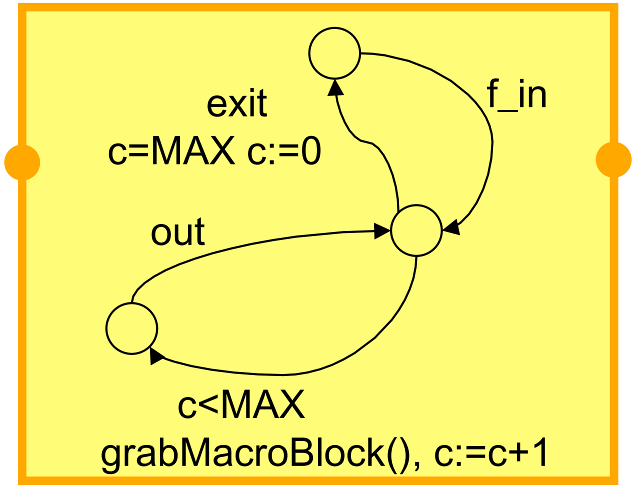


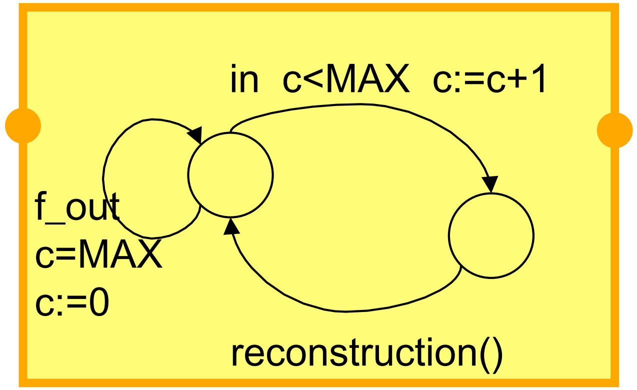
GrabMacroBlock: splits a frame in (W*H)/256 macro blocks, outputs one at a time

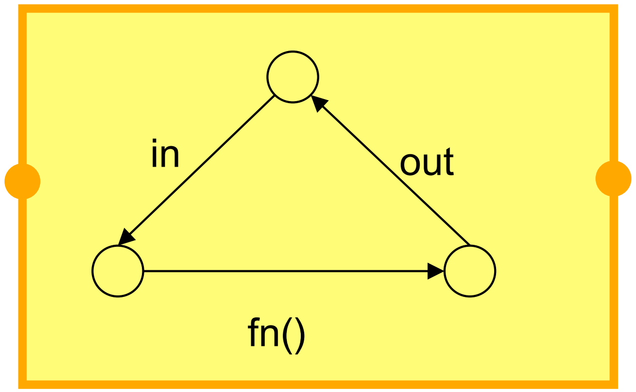
Reconstruction: regenerates the encoded frame from the encoded macro blocks.

: buffered connections

Example – MPEG4 Video Encoder







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

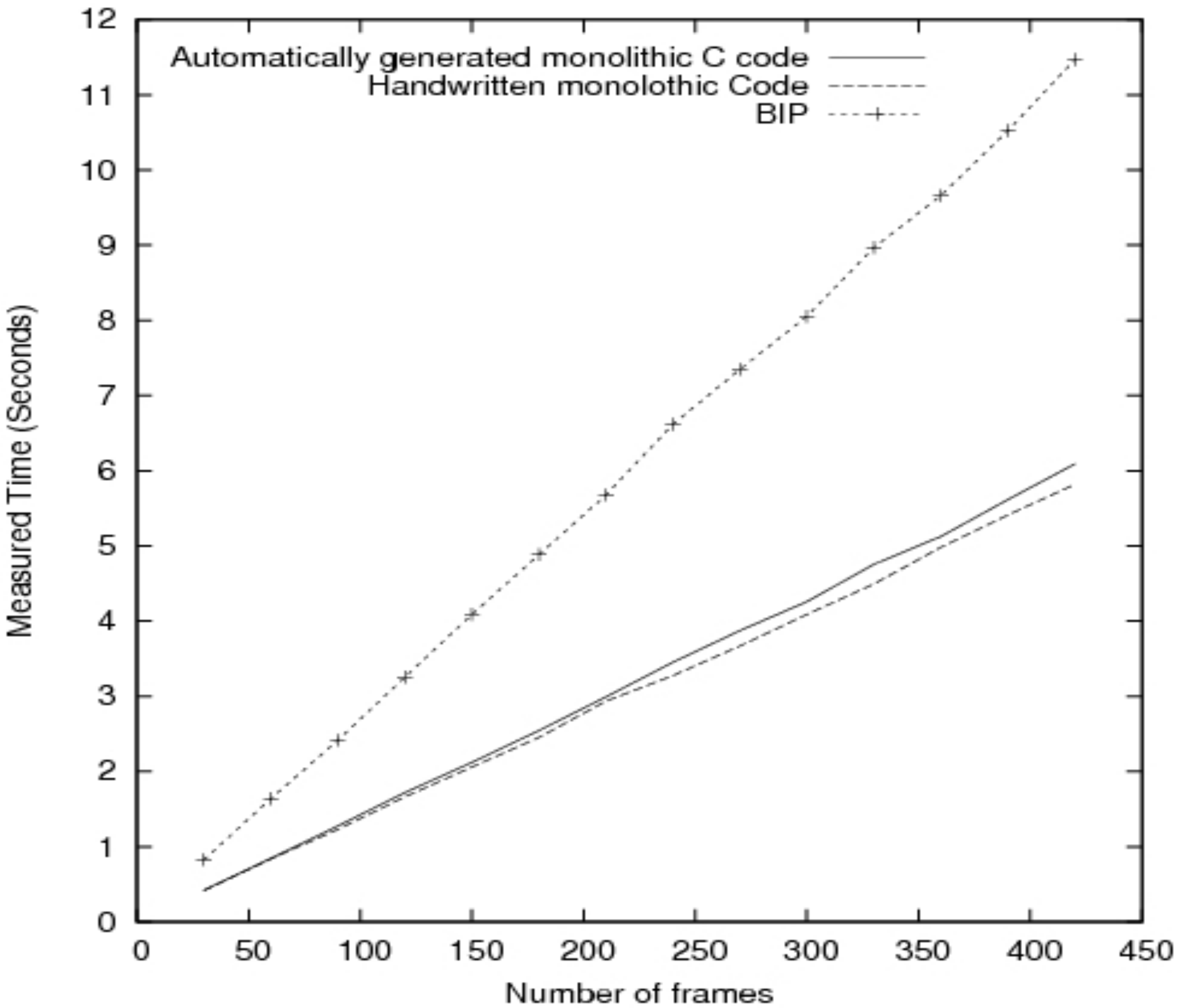
Axample – MPEG4 Video Encoder: Results

- ~ 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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Results

Papers

- A. Basu, Ph. Bidinger, M. Bozga and J. Sifakis. Distributed Semantics and Implementation for Systems with Interaction and Priority FORTE, 2008, pp. 116-133.
- Marius Bozga, Mohamad Jaber, Joseph Sifakis: Source-to-source architecture transformation for performance optimization in BIP. IEEE Fourth International Symposium on Industrial Embedded Systems 2009, pp 152-160
- Ananda Basu, Saddek Bensalem, Doron Peled, Joseph Sifakis: Priority Scheduling of Distributed Systems Based on Model Checking. CAV 2009: 79-93
- Borzoo Bonakdarpour, Marius Bozga, Mohamad Jaber, Joseph Sifakis. Incremental Component-based Modeling, Verification, and Performnce Evaluation of Distributed Reset, DISC 09.

Distributed Implementations

- Centralized BIP Engine (FORTE08)
- Weakly decentralized (one Engine per set of conflicting interactions) over Linux using TCP sockets
- Weakly decentralized (one Engine per interaction + Conflict resolution with alpha-core) over Linux using TCP sockets

Discussion

- Study different distributed implementations from fully decentralized to fully centralized ones
- Use existing distributed algorithms for multiparty interaction and conflict resolution e.g. maximal matching algorithm
- Prove correctness by using composability techniques - non interference of features of the composed algorithms
- Performance evaluation – tradeoffs wrt two criteria:
  - degree of parallelism
  - overhead for coordination
- Implementation tools and case studies.

Thank You