A type system to avoid runtime errors for Multi-ML

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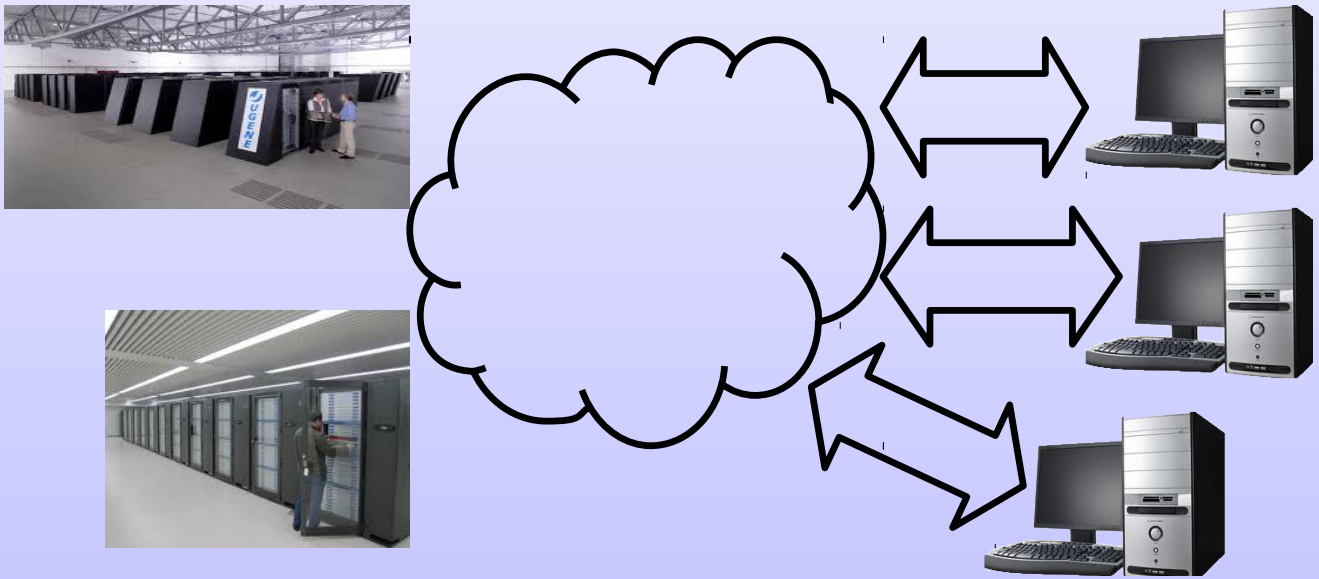
University of Paris-East, France

[2] Former LACL members

Outline

Outline

Q: Cloud/Grid computing?



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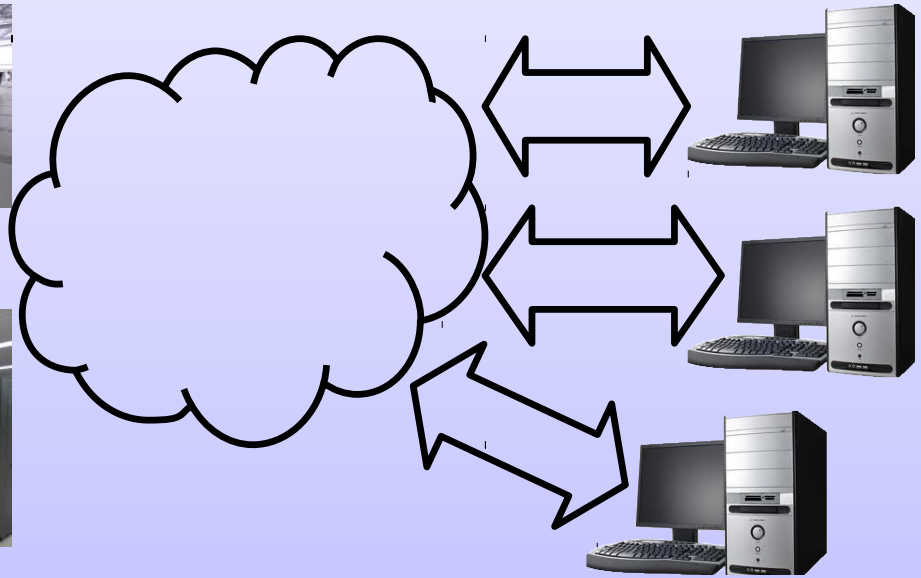

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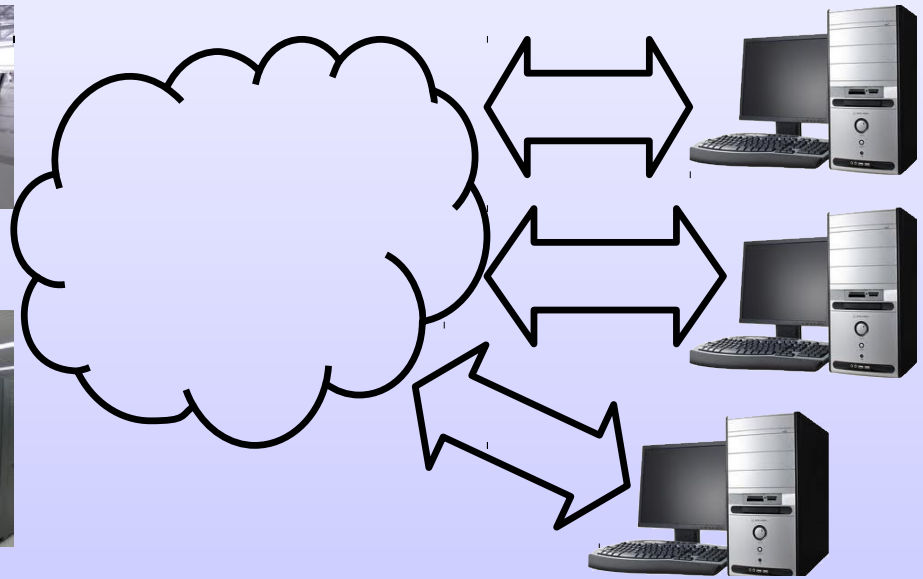

Bugs and crashing of HPC programs

- Portability, scalability ⇒ software-hardware bridging model
- Safety, cost ⇒ Structured parallelism ⇒ (Multi-)BSP

Q: why structured parallelism?

Debugging and verification

Reasoning about cost

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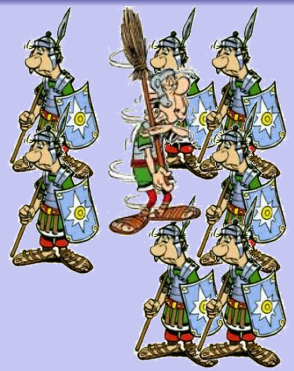

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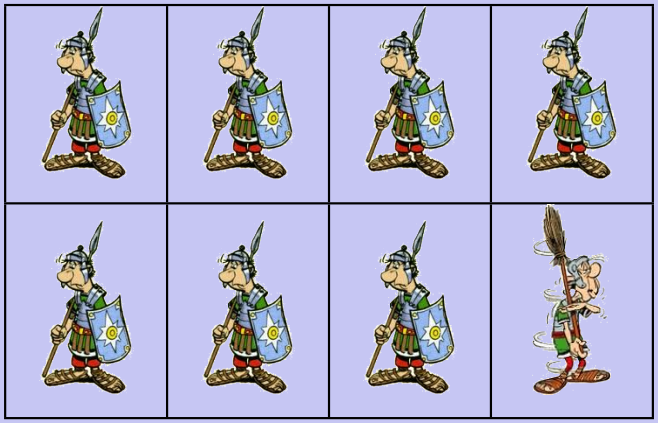

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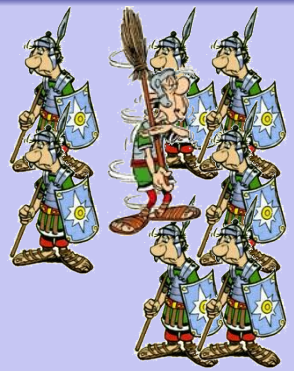

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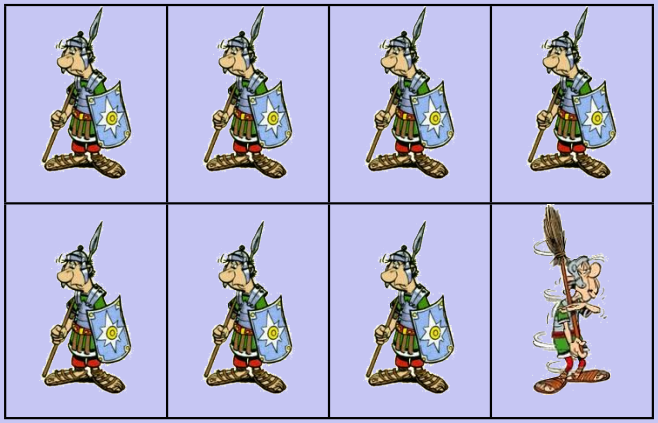

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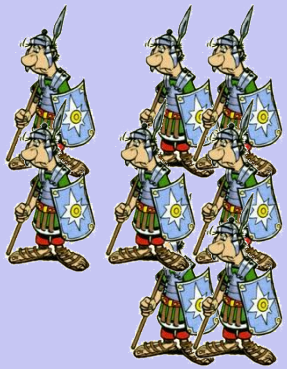

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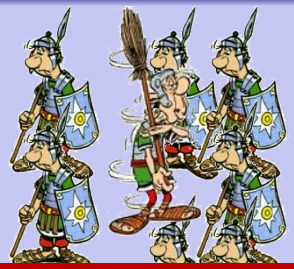

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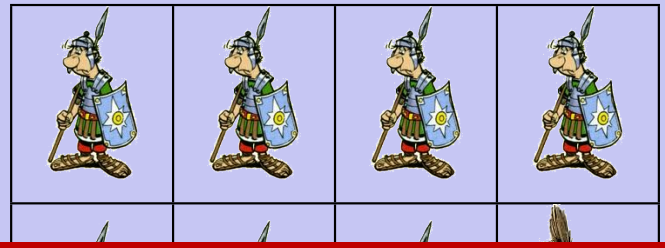
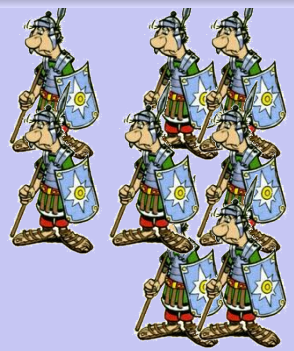


Considered solutions

"*Send-receive considered harmful*" (Sergei GORLATCH)

1. (Multi-)BSP extension of a functional language
2. Types and Semantics



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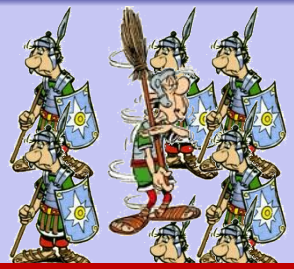

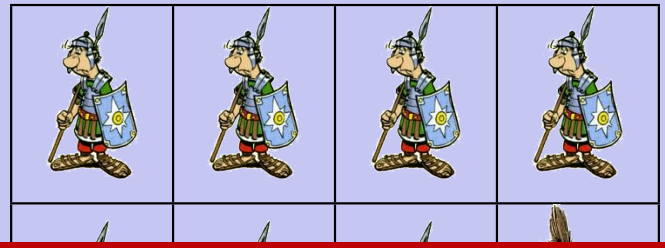

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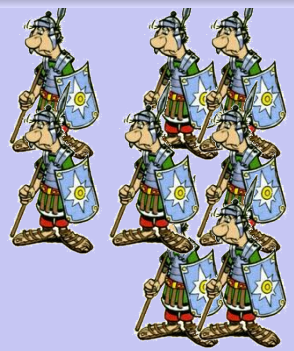

Q: What is OCaml?

A general-purpose (but functional spirit) programming language

- Rich static type system
- Many features: lambda, objects, modules, GADT, *etc.*
- Industrial strength (many tools and libraries)

Some short examples

```
# let compo f g x = g (f x)
# type 'a list = Null | Node of 'a * 'a list
# let rec length l = match l with
    | Null → 0
    | Node (data,next) → 1+(length next);;
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And now...

1. Multi-BSP (hierachical version of BSP)
2. Multi-BSP extention for OCaml (Multi-ML)

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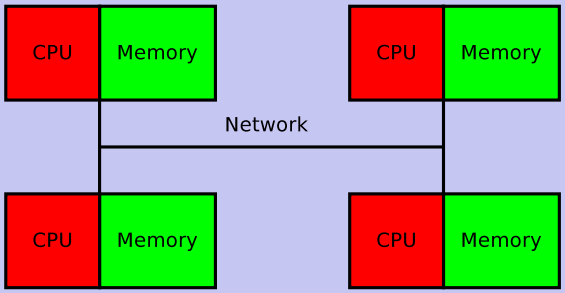
Distributed computing



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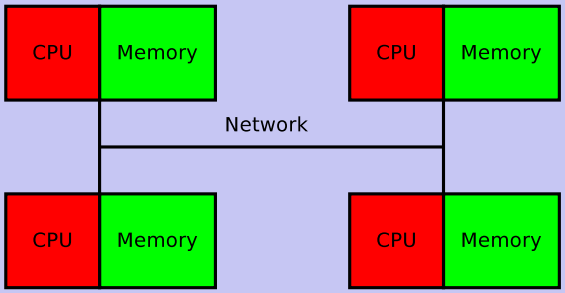

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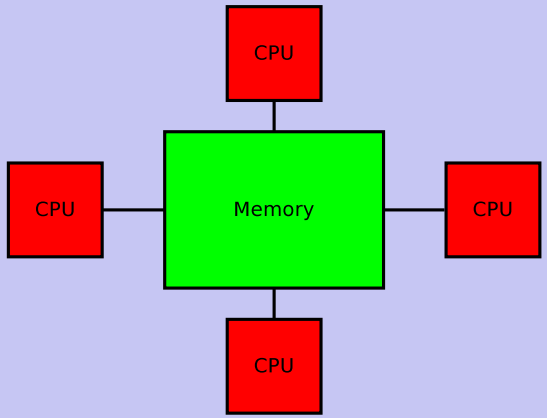

Multi-core

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The BSP computer

Defined by:

- **p** pairs CPU/memory
- Communication network (**g**)
- Synchronisation unit (**L**)

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- Deterministic
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Super-steps execution

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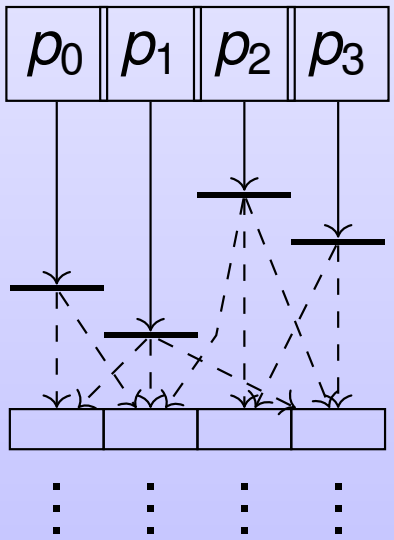

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barrier ($\oplus$**L**)

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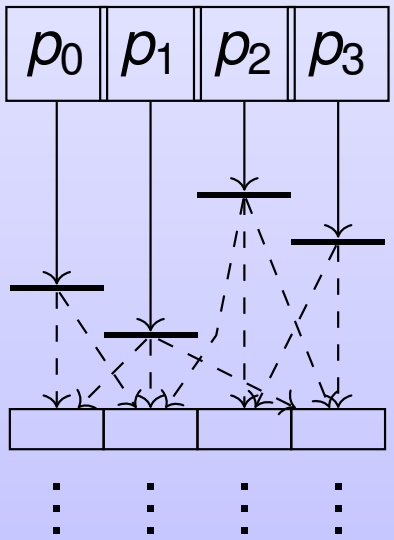

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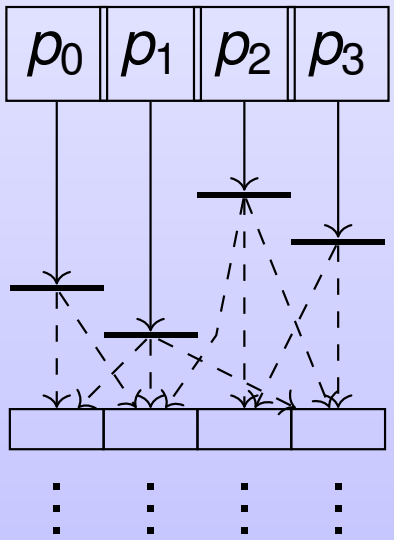

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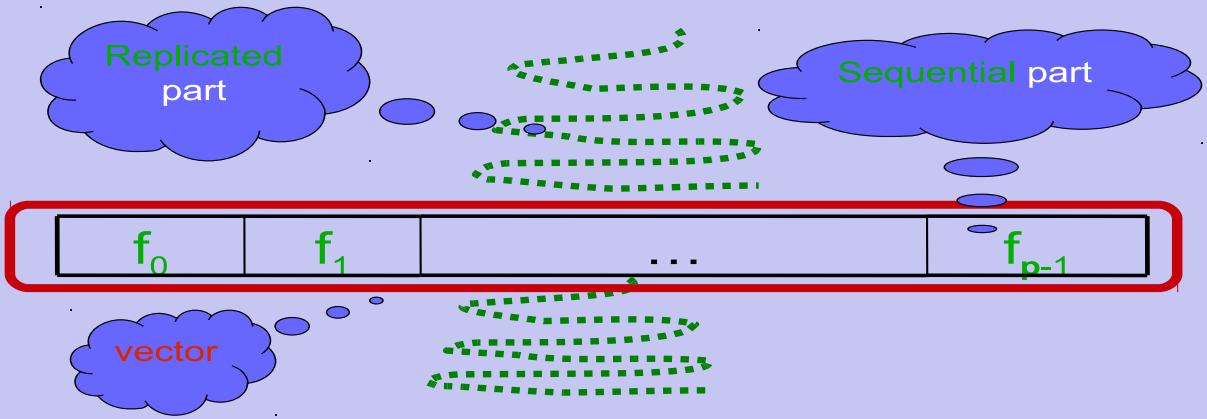
Main idea

Parallel data structure $\Rightarrow$ vectors:



1. $\langle v_0, \ldots, v_{p-1} \rangle : \alpha\ par \equiv v_i$ on node i
2. Four primitives $\Rightarrow$ simple semantics

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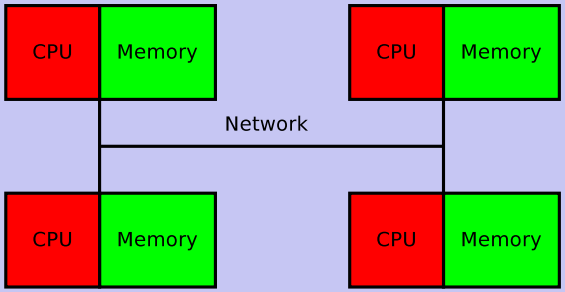

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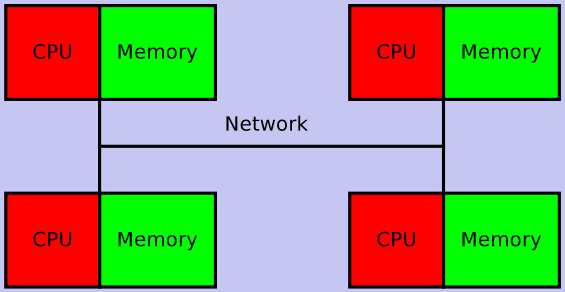

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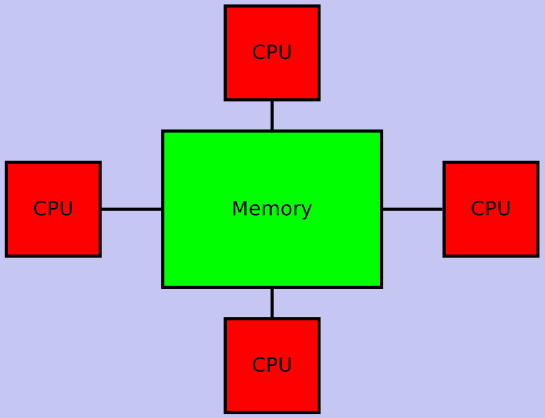

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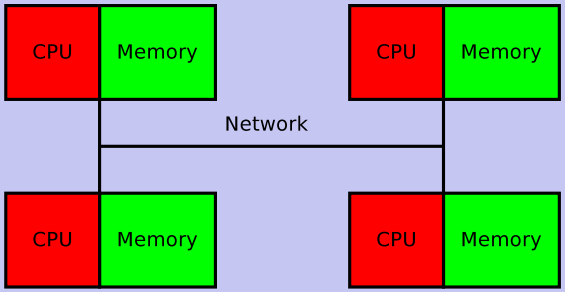

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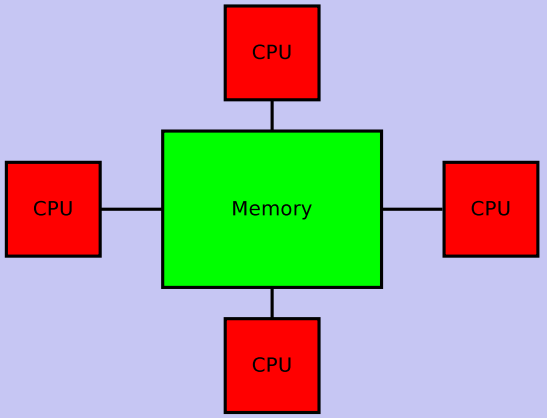

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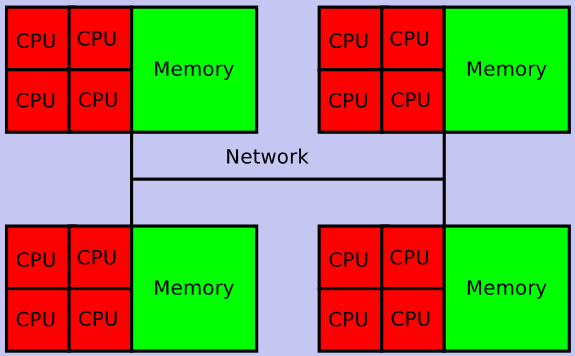
Hybrid model



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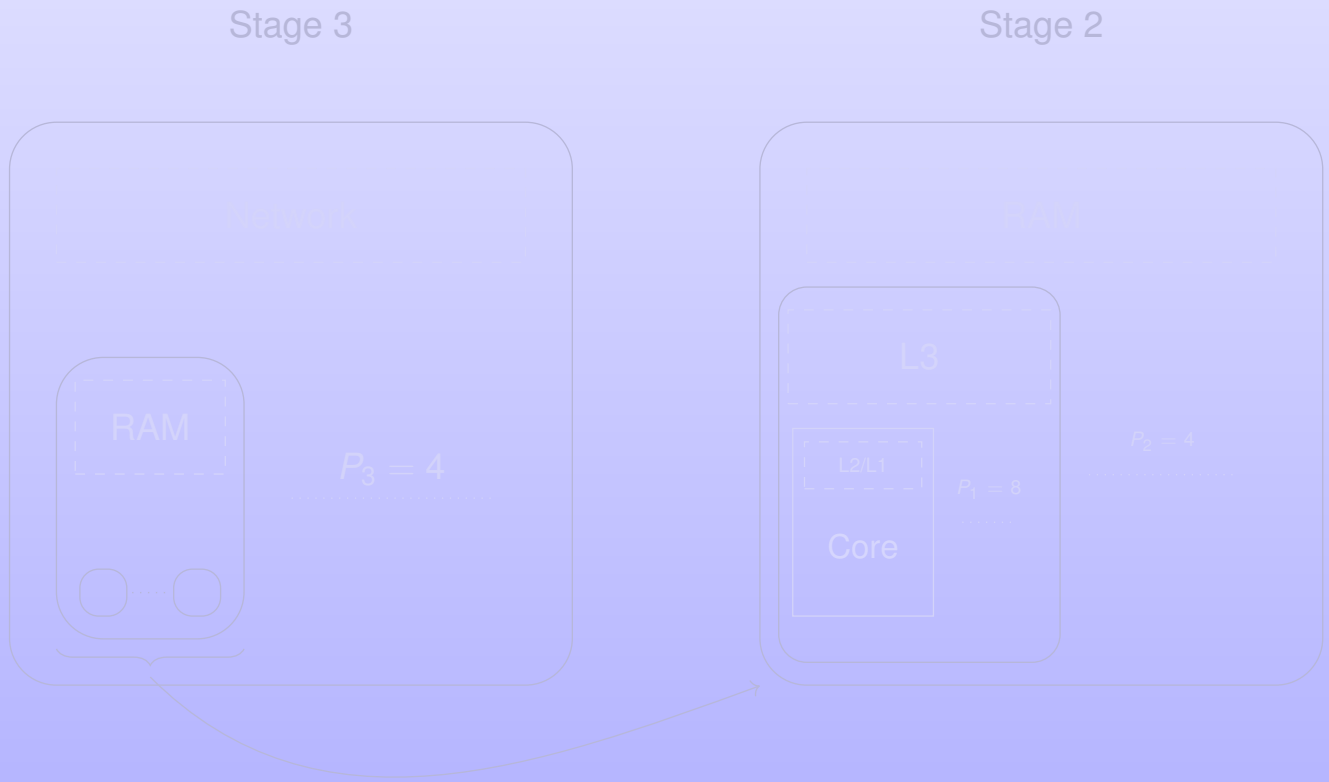
1. A tree structure of nested components
2. Where nodes have a storage capacity
3. And leaves are processors
4. With sub-synchronisation capabilities



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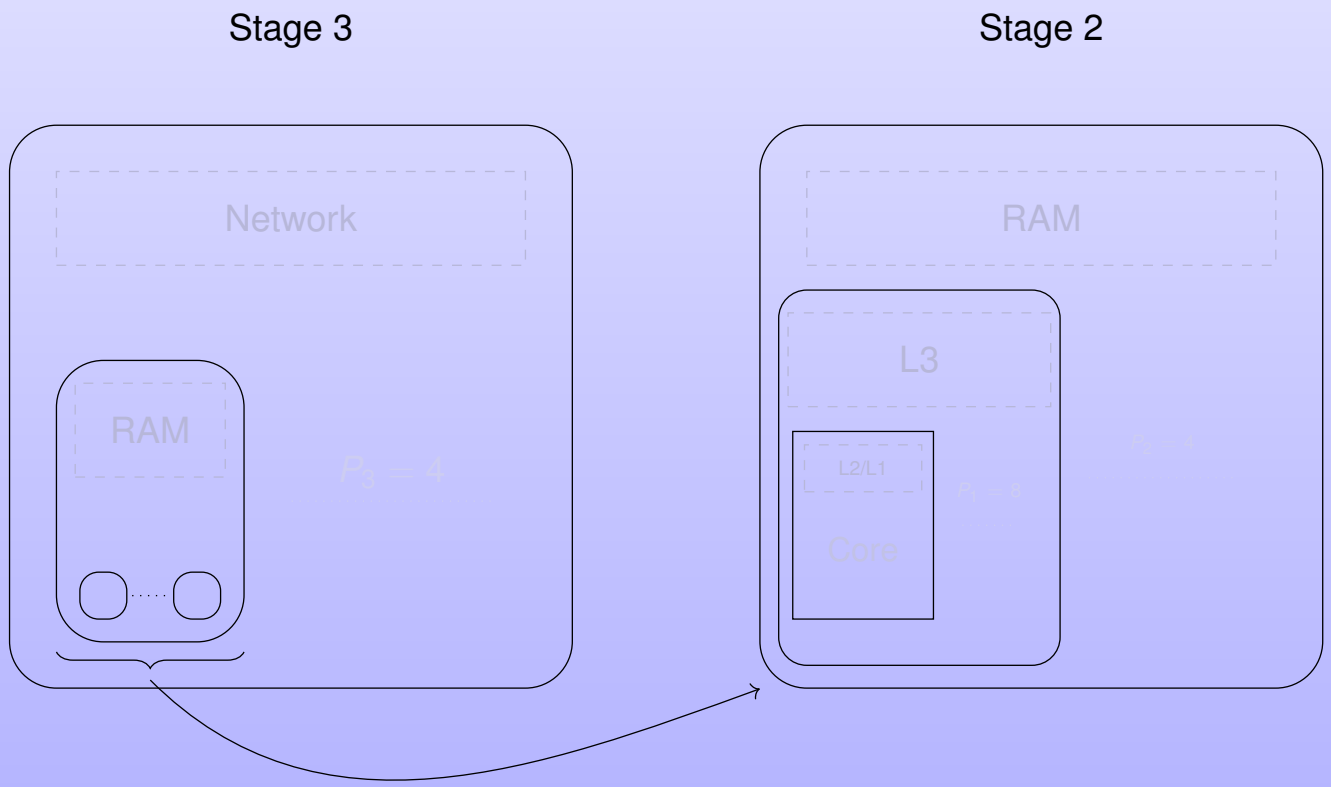

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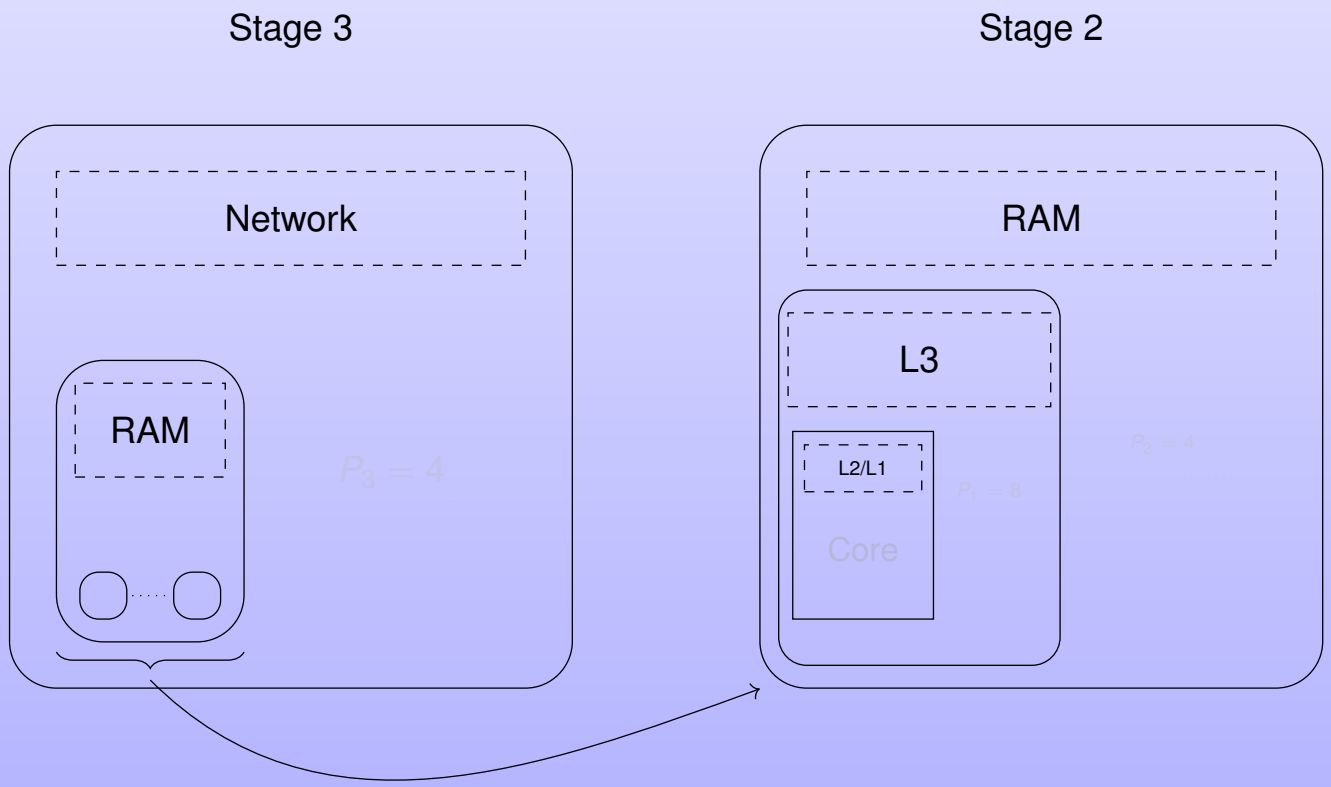

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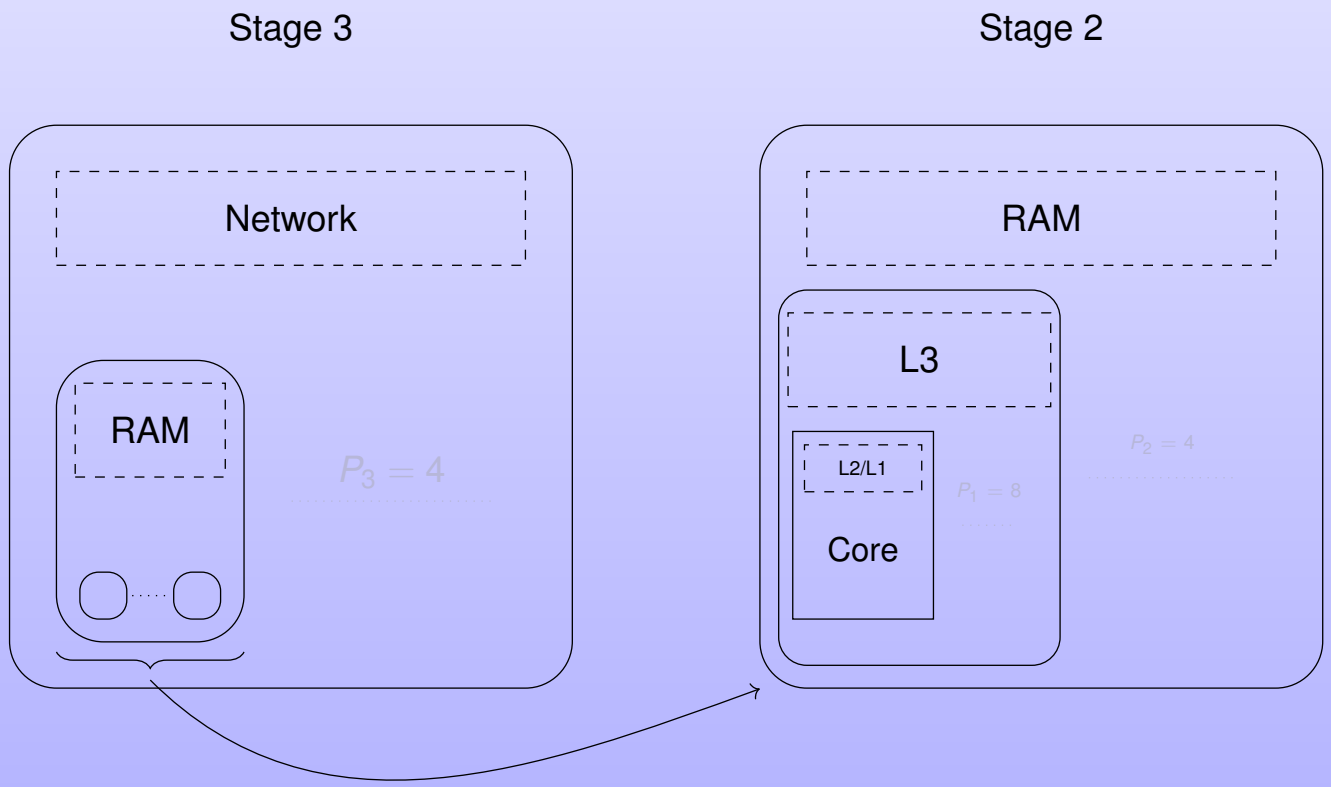

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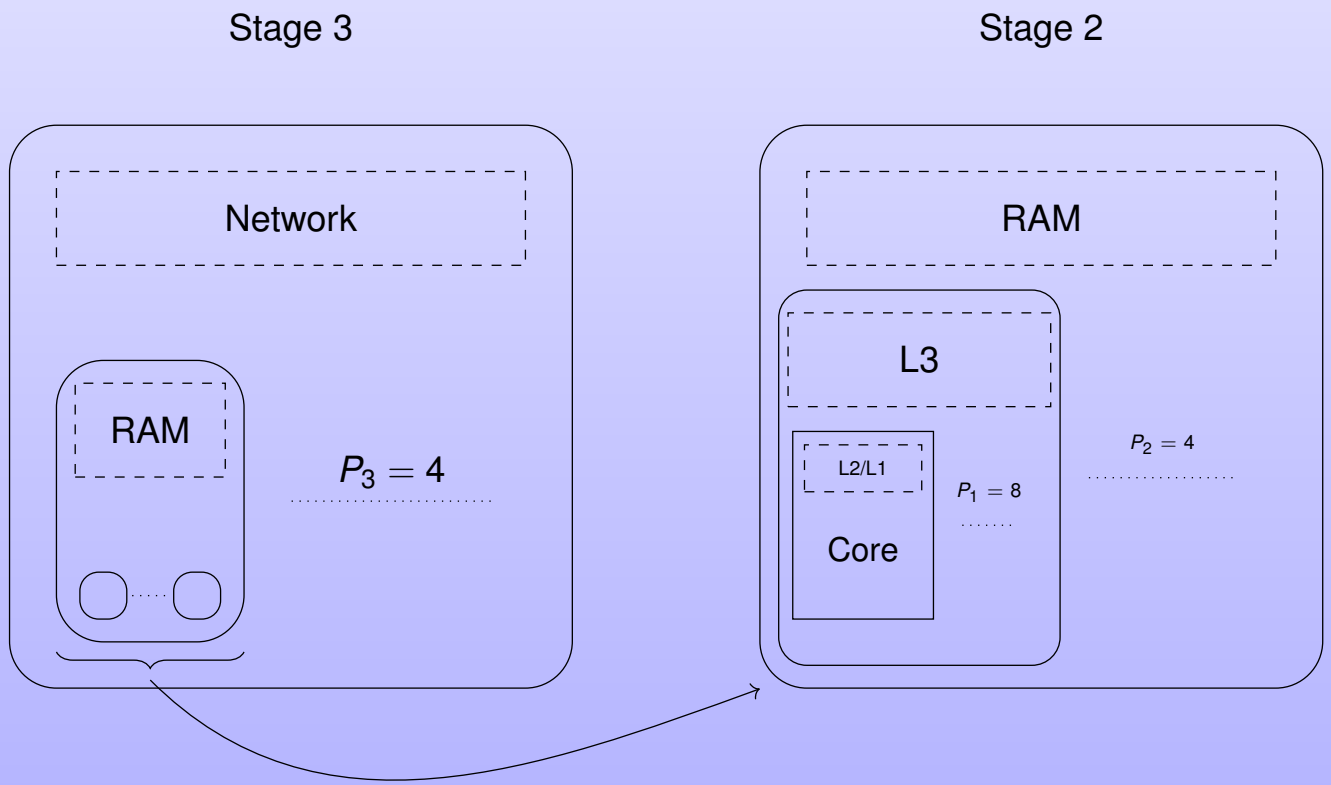
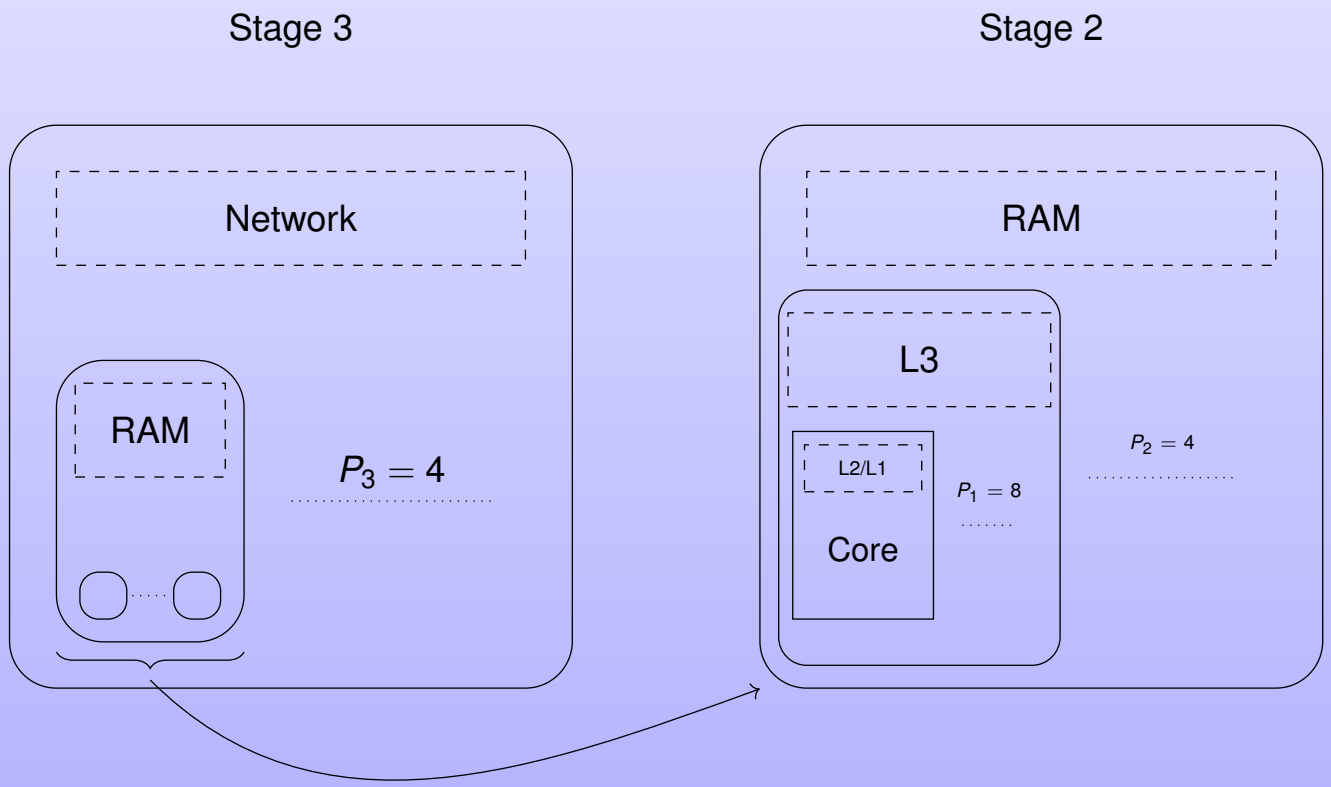


Q: What is MULTI-BSP?

- Stage 3: 4 nodes with a network access
- Stage 2: one node has 4 chips plus RAM
- Stage 1: one chip has 8 cores plus L3 cache
- Stage 0: one core with L1/L2 caches



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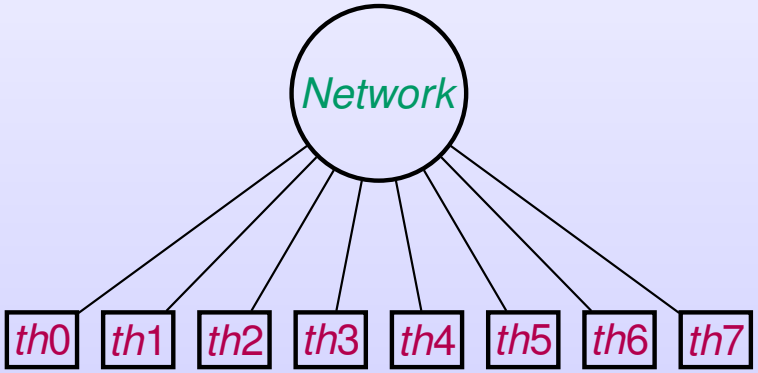

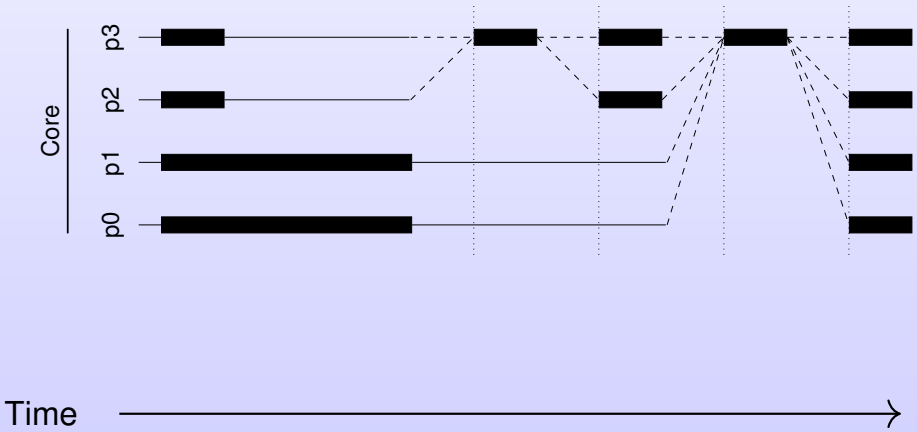

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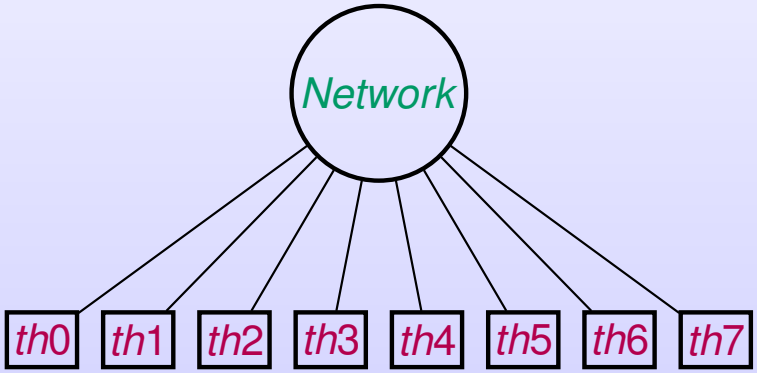

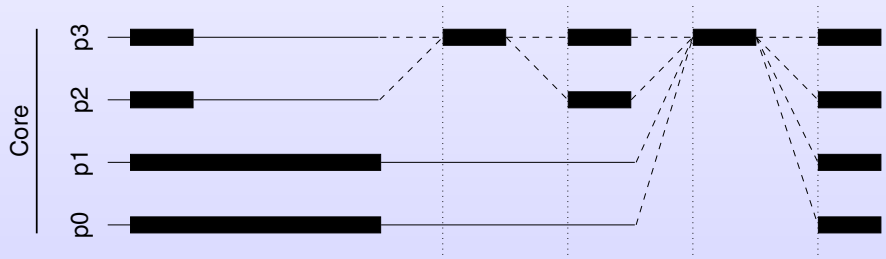

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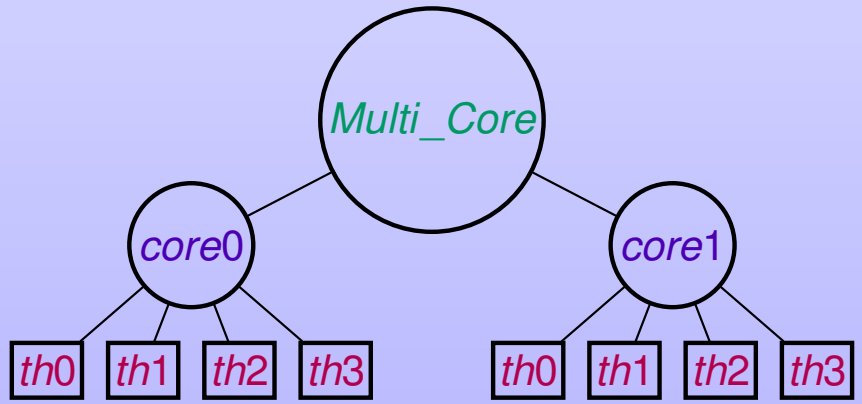

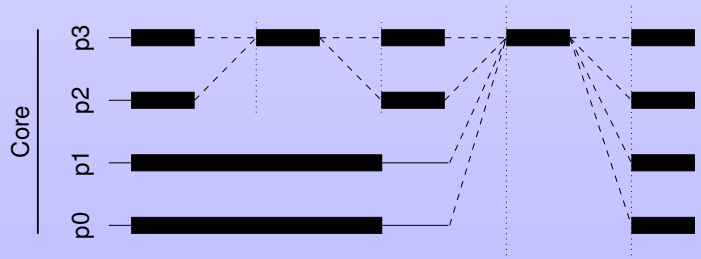

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Basic ideas

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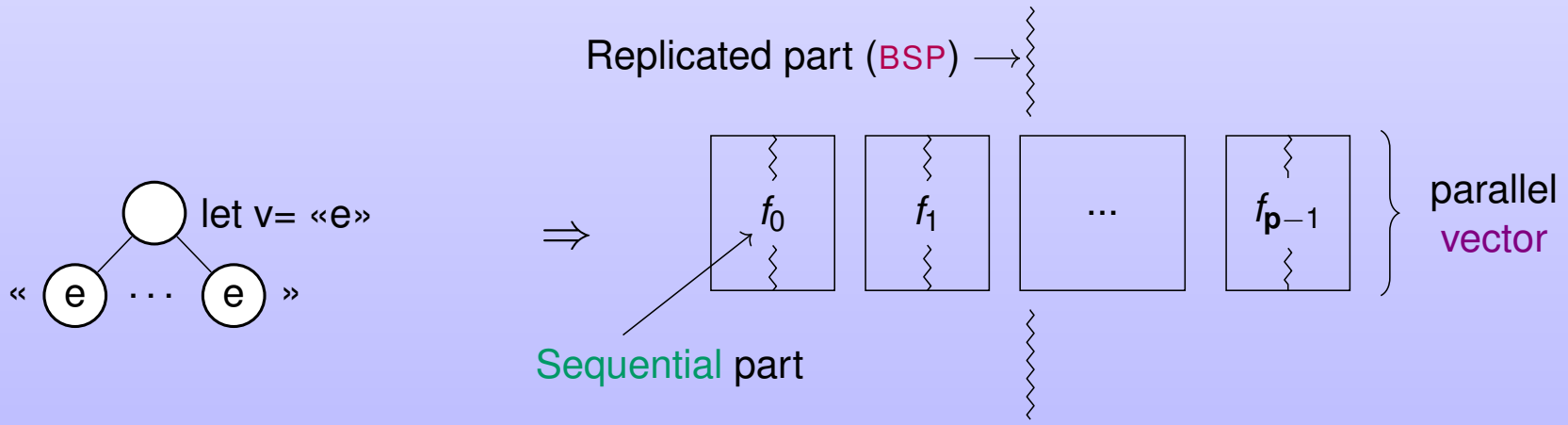

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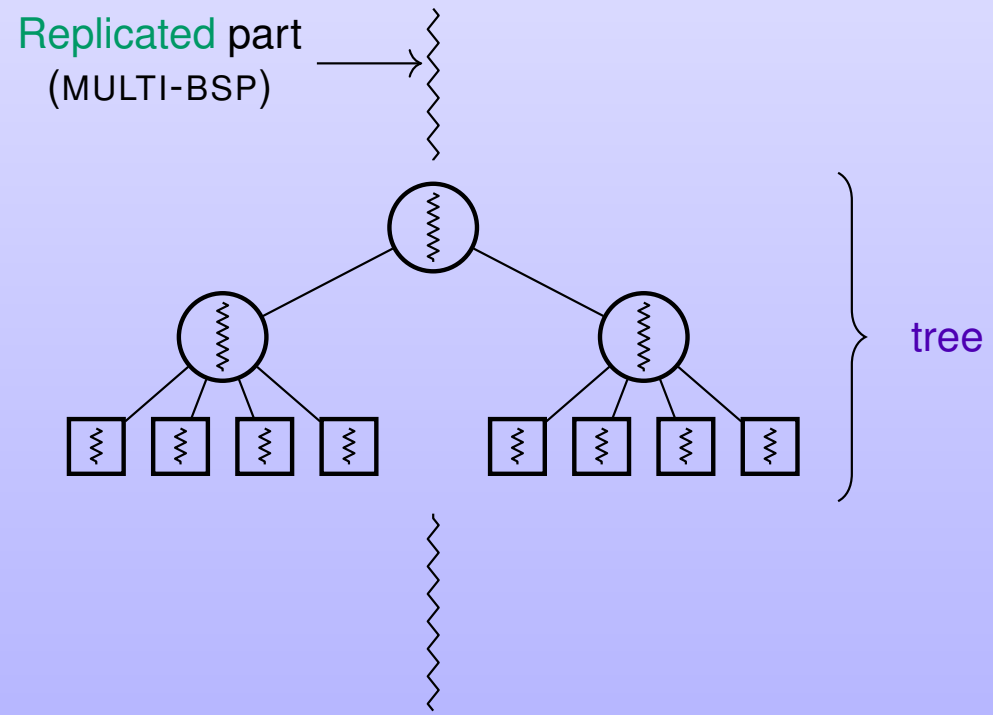
Basic ideas

- BSML code on every stage of the MULTI-BSP architecture
- Specific syntax over ML: eases programming
- *Multi-functions* that recursively go through the MULTI-BSP tree



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Recursion structure

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    ...
    ≪ f [args] ≫
    ... **in** v
  where leaf =
    (∗ OCaml code ∗)
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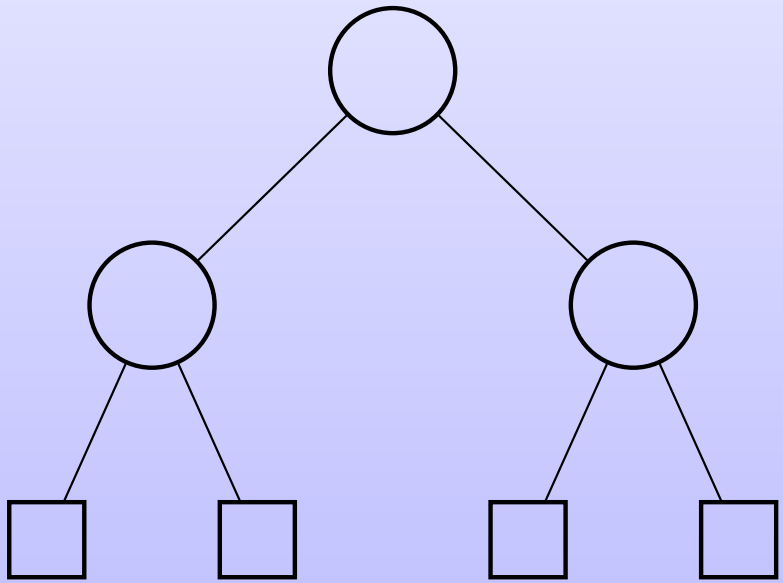

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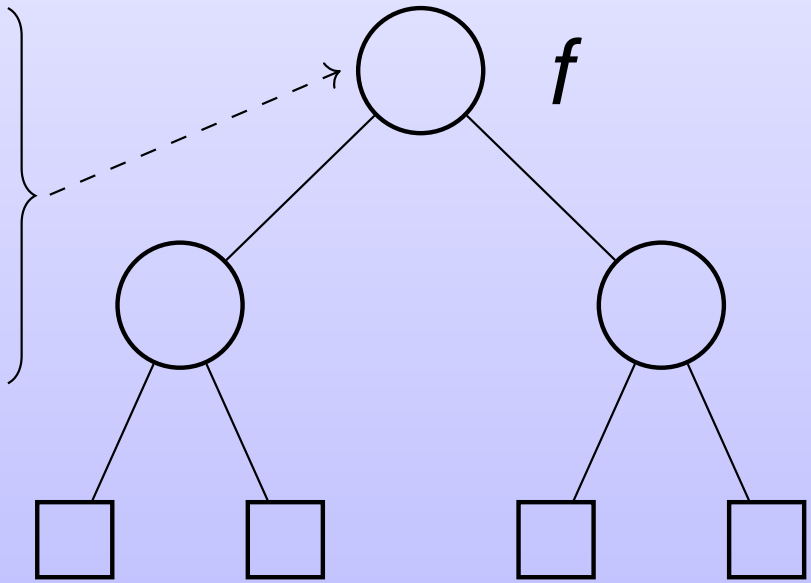

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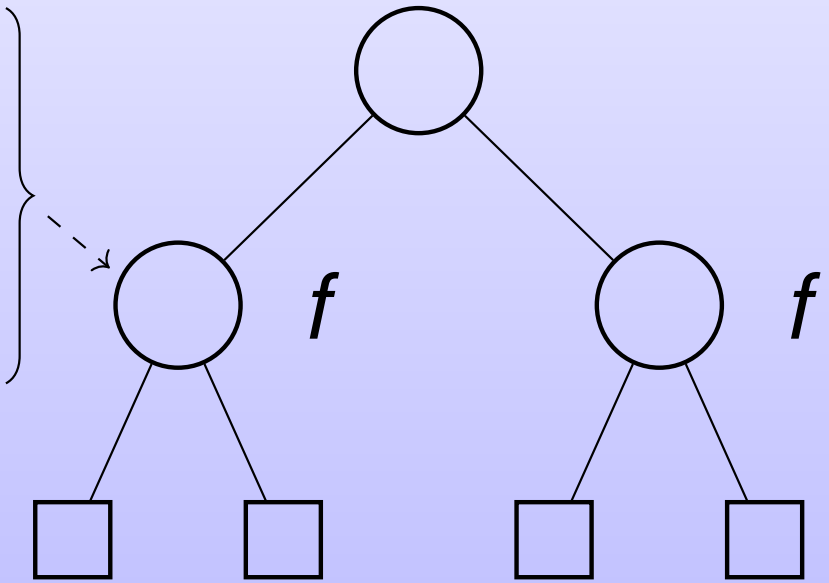

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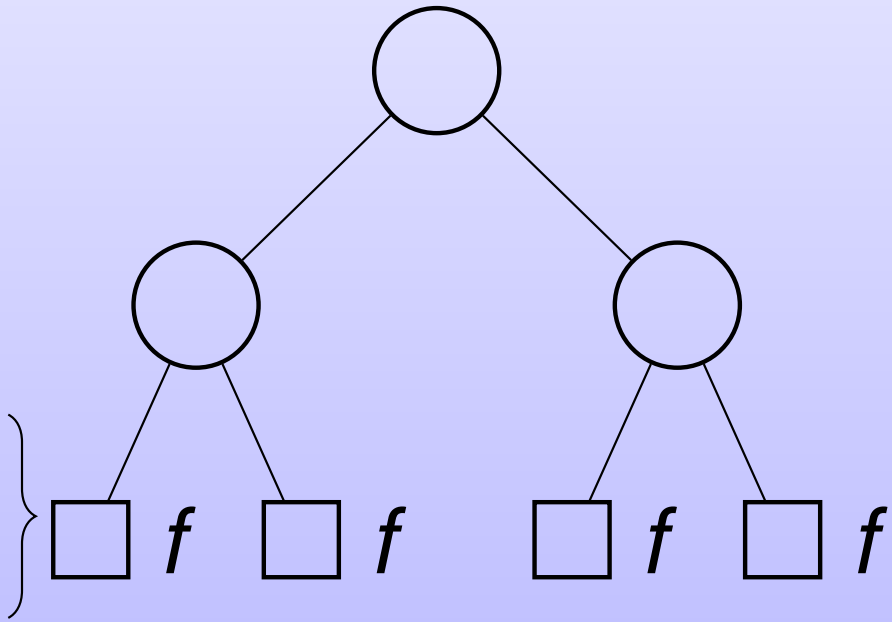

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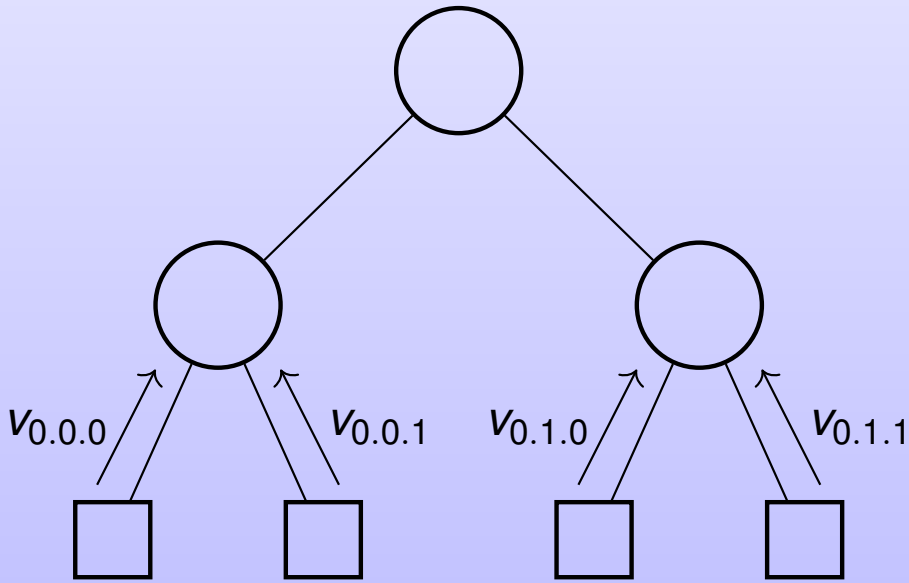

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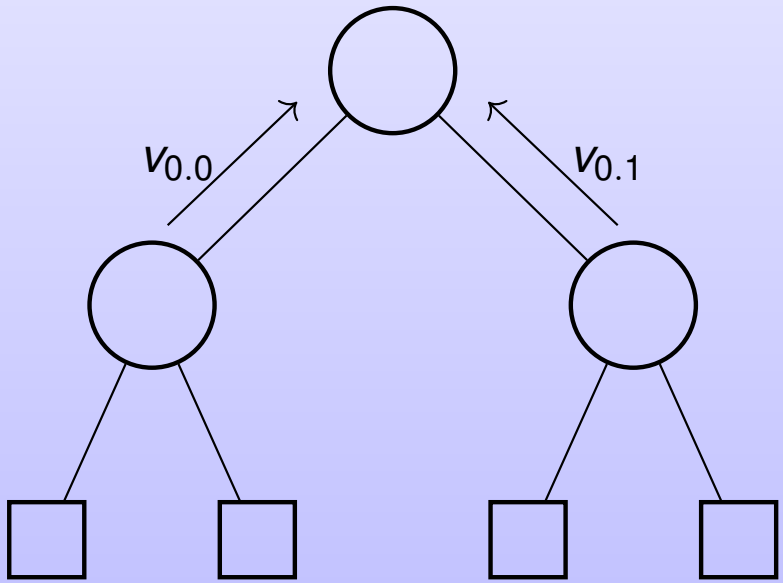

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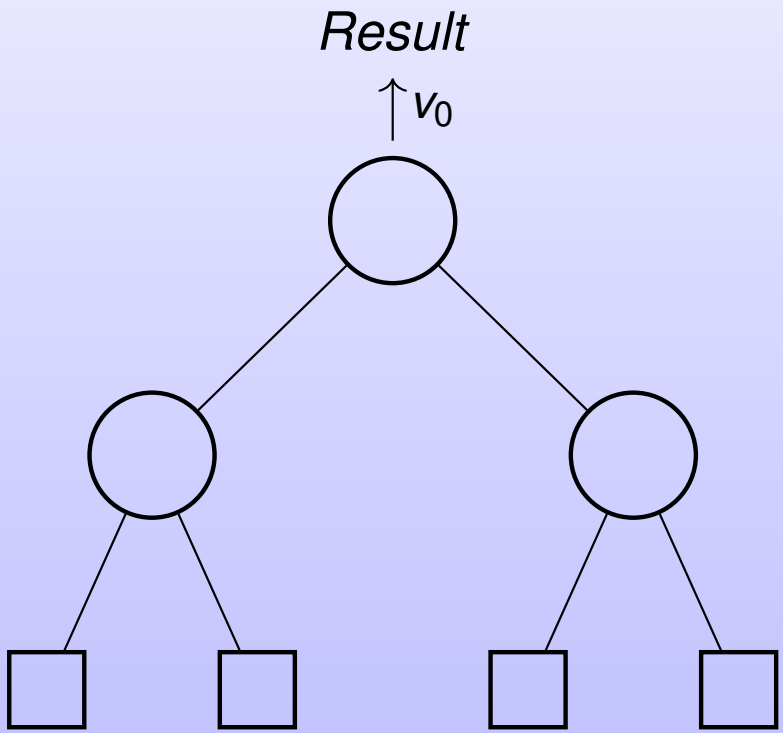

Outline

Q: What are the errors?

Parallel program safety

- Replicated coherency

Replicated coherency

```
if random_bool () then
  multi_fct ()
else
  (fun _ → ...) ()
```

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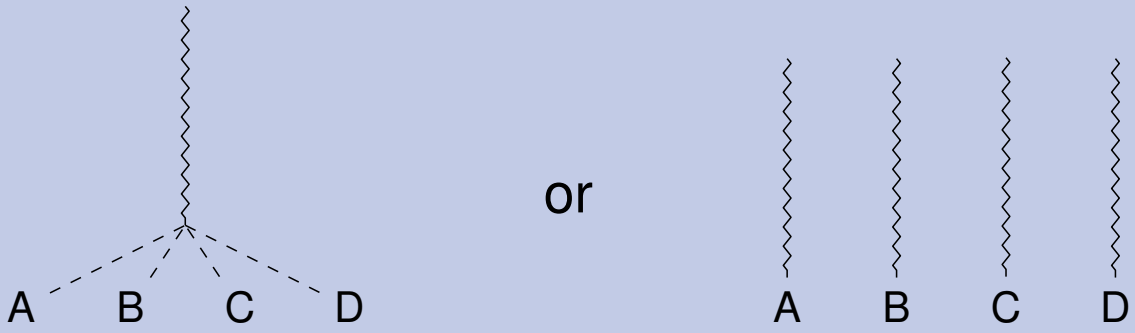
Why ?



Replica

```
if random_bool () then
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else
  (fun _ → ...) ()
```

Q: What are the errors?

Parallel program safety

- Replicated coherency
- Level (memory) compatibility

Level (memory) compatibility

let v = ≪ **let multi** f x = ... ≫

let z = v+$**pid**$ // outside vectors

≪ v+$**pid**$ ≫ // outside nodes (e.g. inside leafs)

Q: What are the errors?

Parallel program safety

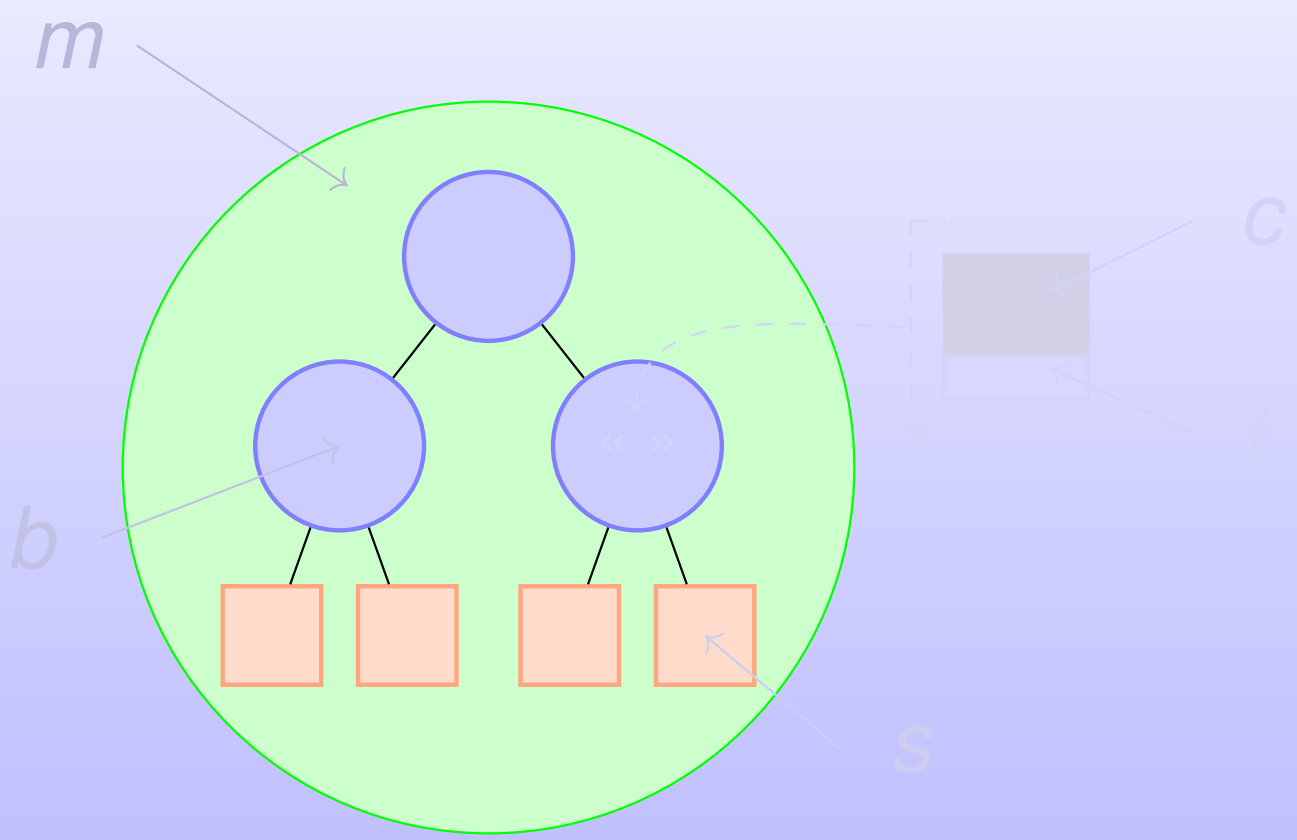
- Replicated coherency
- Level (memory) compatibility
- Control parallel structure imbrication
  - vector
  - tree

Parallel structure imbrication

$\ll$ **let** v = $\ll$ 1 $\gg$ **in** v $\gg$

let v = $\ll$ 1 $\gg$ **in** $\ll$ v $\gg$

Type localities



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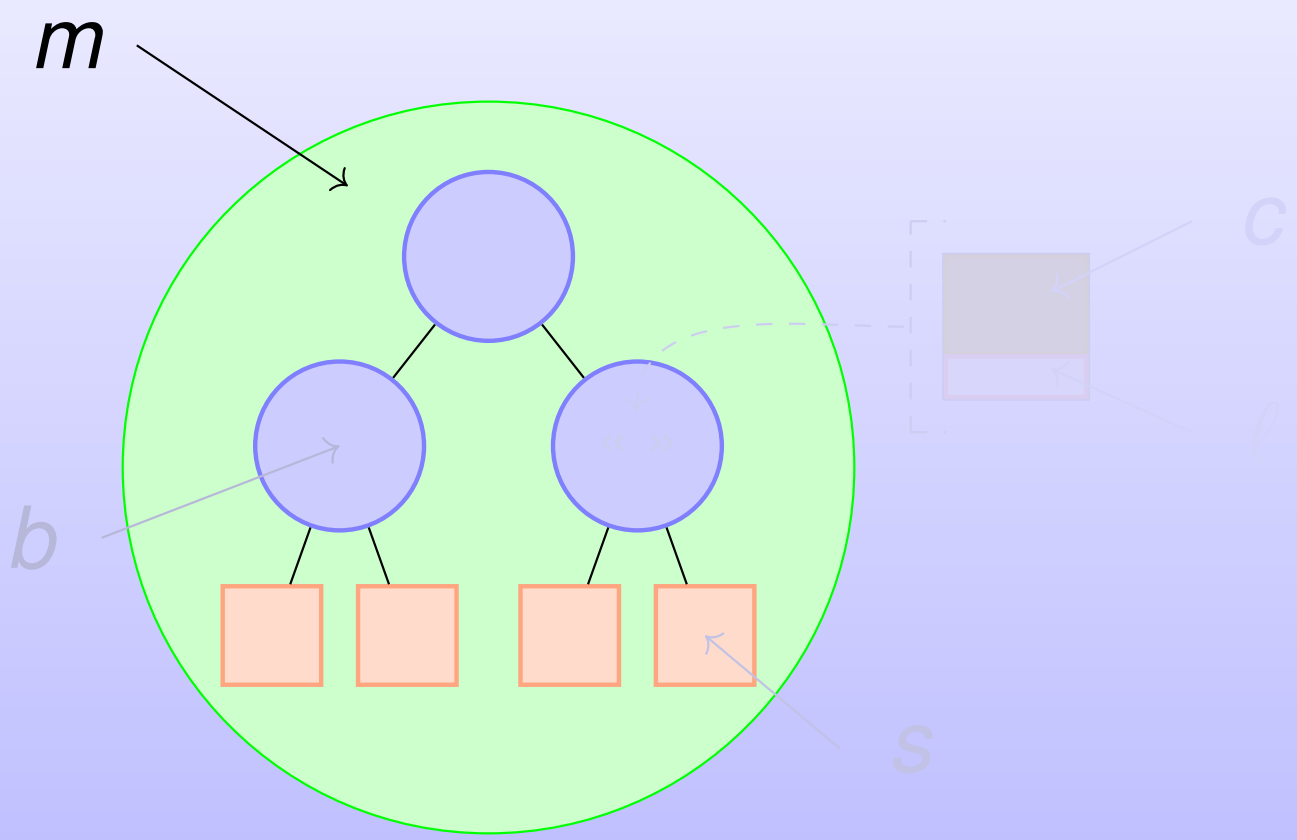

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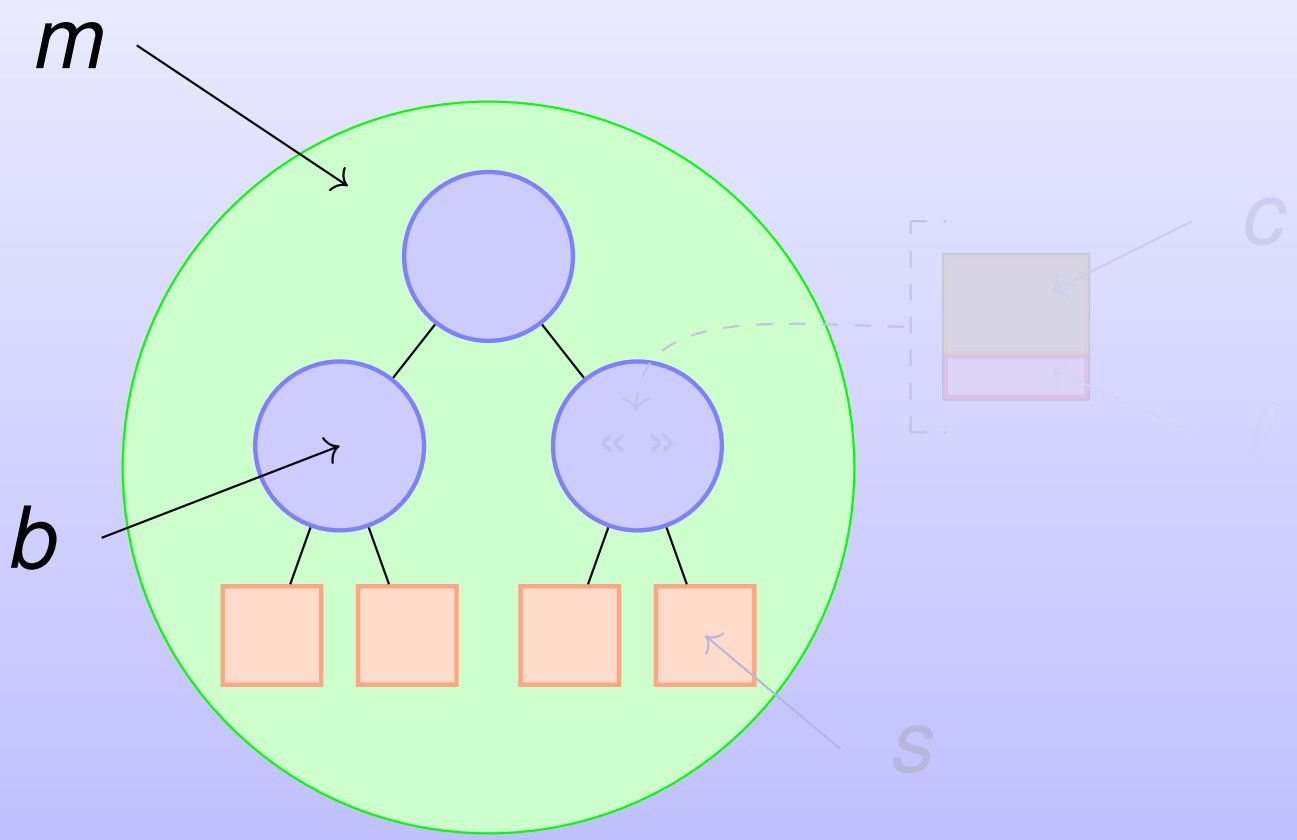

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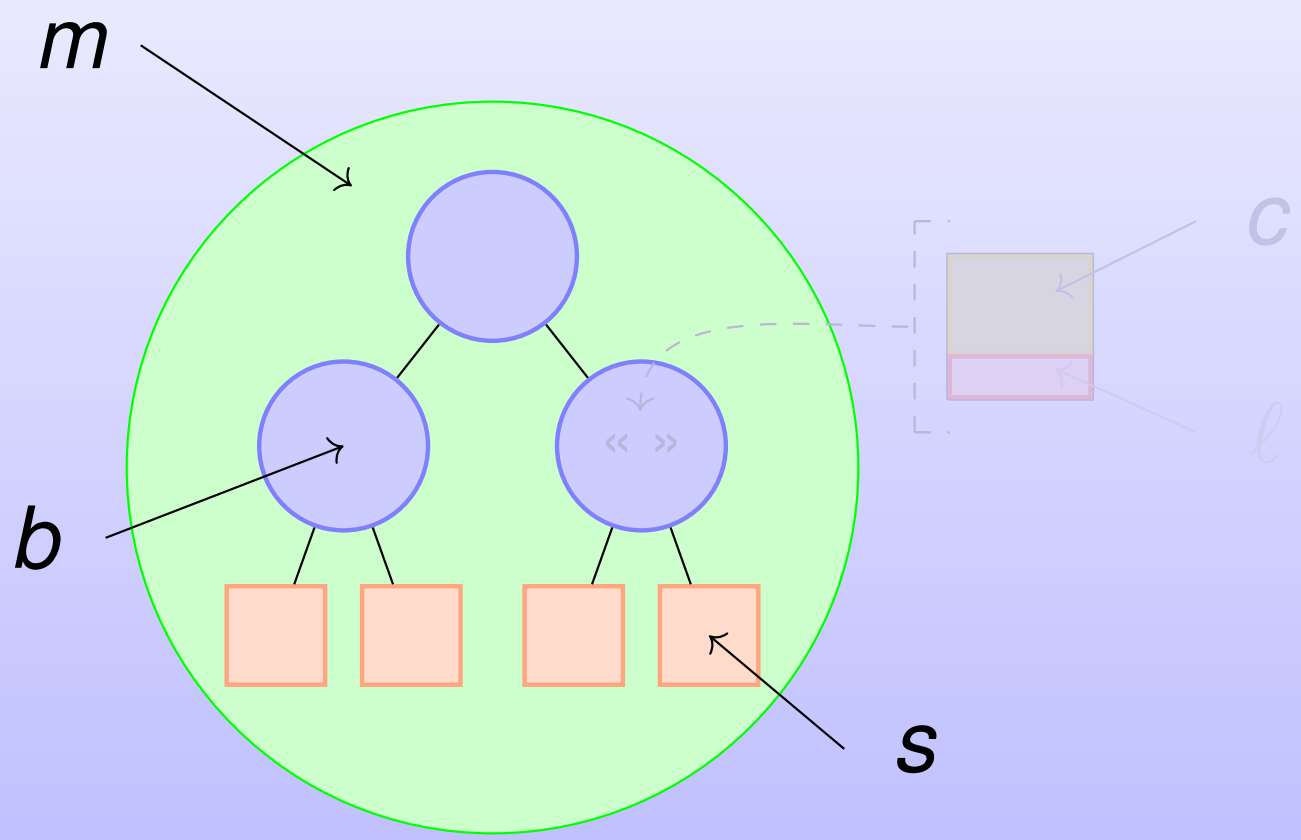

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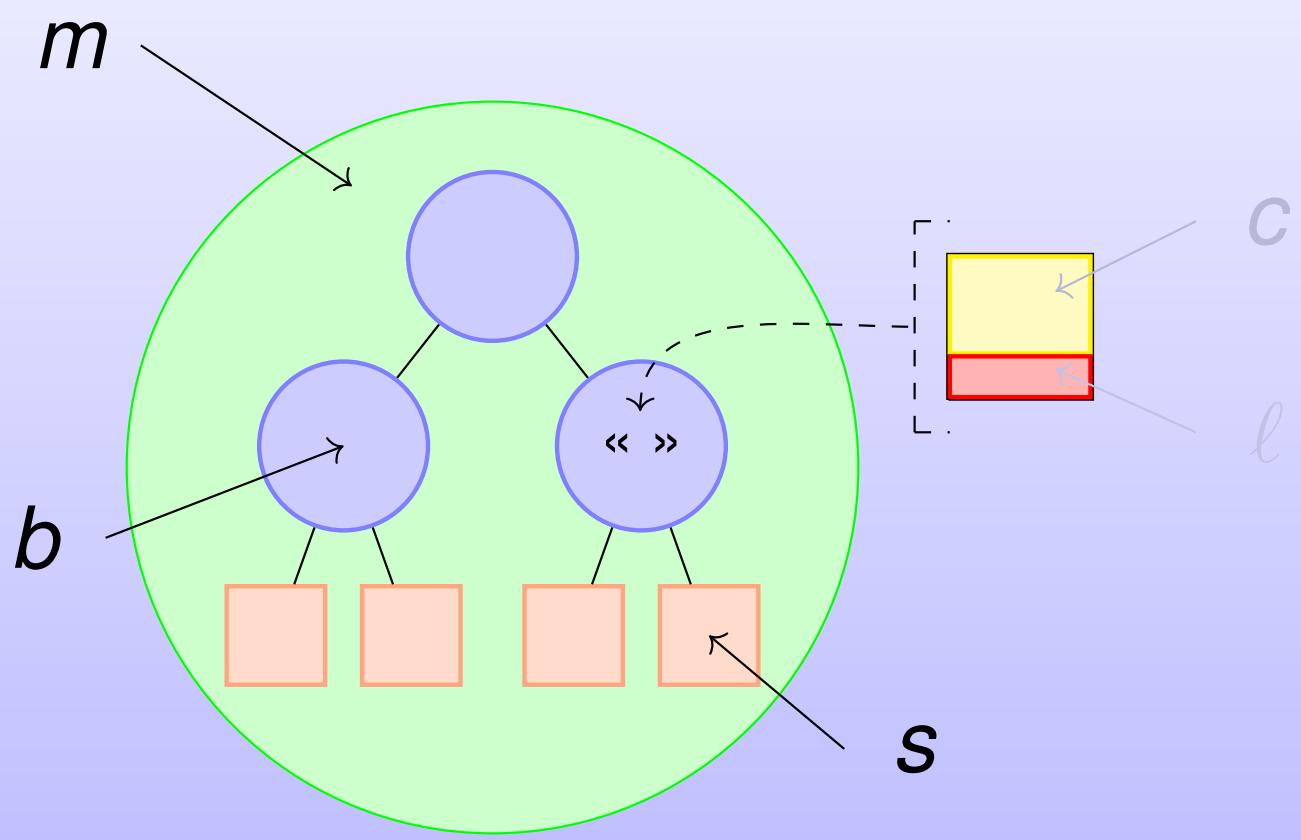

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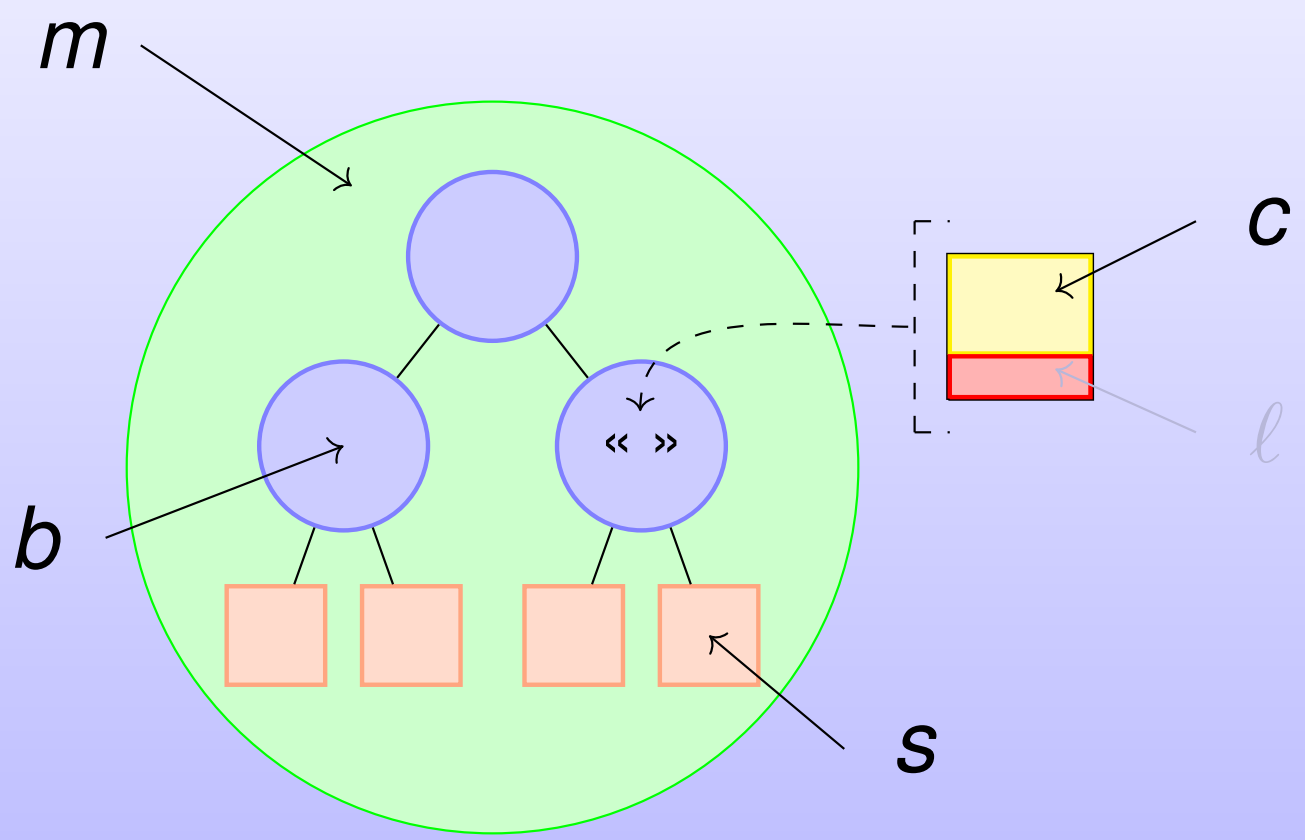

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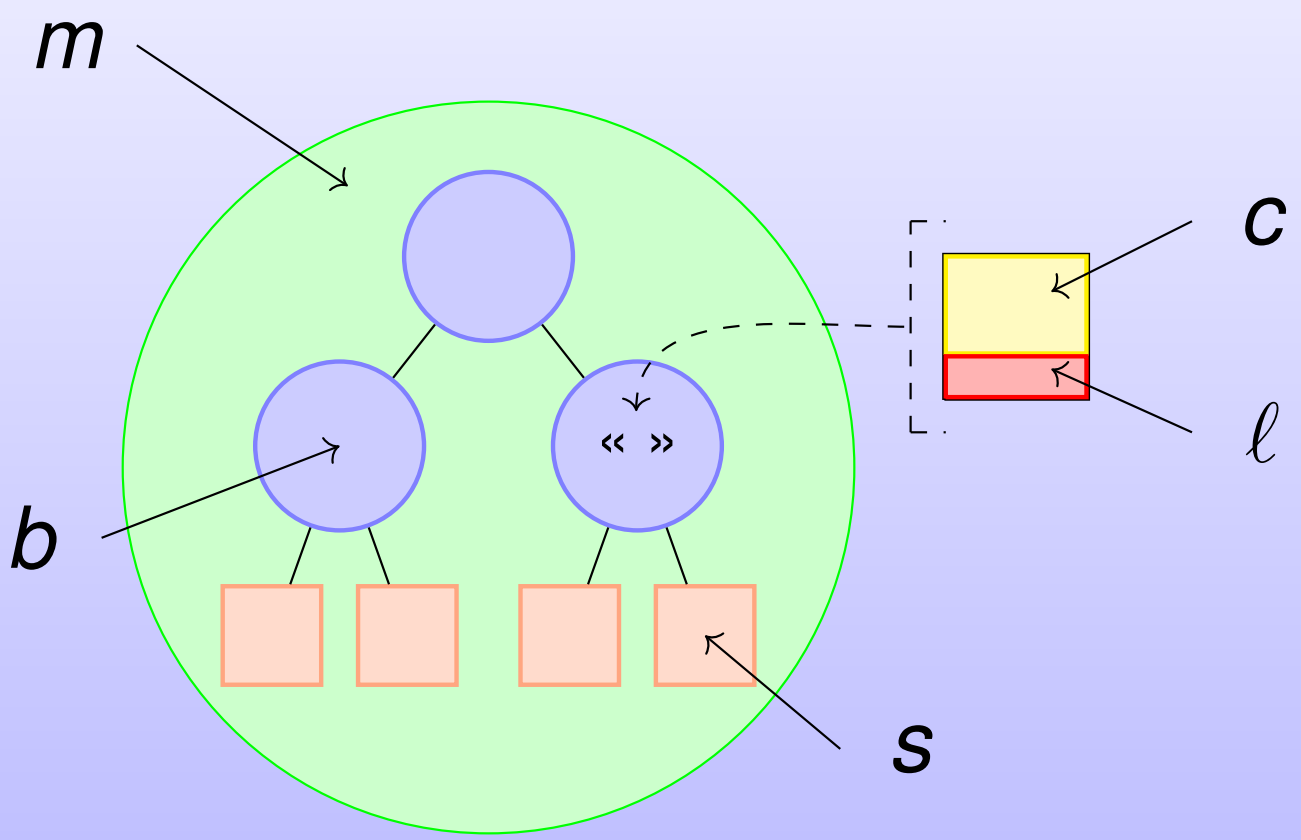
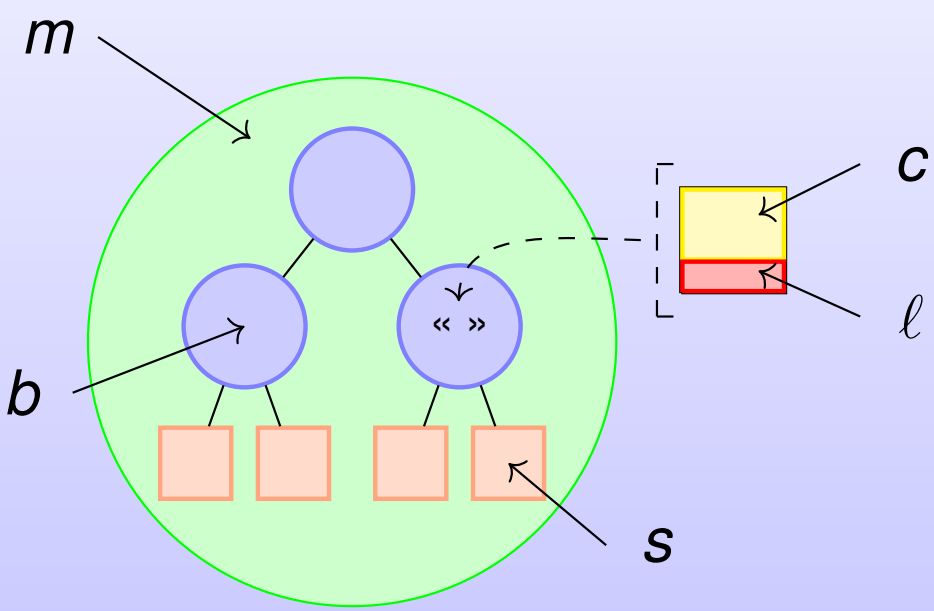


Type annotations



Type grammar

τ	$::=$	
	α_π	*type variable*
	$\texttt{Base}_\pi$	*base type*
	$(\tau, \tau)_\pi$	*pair*
	$\tau\ \texttt{Par}_b$	*vector*
	$\tau\ \texttt{Tree}_\pi$	*tree*
	$(\tau \xrightarrow{\pi} \tau)_\pi$	*arrow type*

$\pi \quad ::= m|b|c|l|s$

Q: What are the types?

Latent effect as annotations

$$(\tau \xrightarrow{\pi} \tau)_{\pi'}$$

Where π is the effect *emitted* by the evaluation and π' the locality of definition.

A BSP function

```
# let f = fun x →
    let v = ≪ ... ≫ in 1

−: val f : ('a_'z −(b)→ int_b)_m
```

$$f : ('a_{'z} \xrightarrow{b} int_b)_m$$

Q: What are the constraints?

Definability: $\blacktriangleleft$

$$
\begin{array}{rcl}
s, b, m & \blacktriangleleft & m \\
b & \blacktriangleleft & b \\
l, c & \blacktriangleleft & c \\
l, c & \blacktriangleleft & l \\
s & \blacktriangleleft & s
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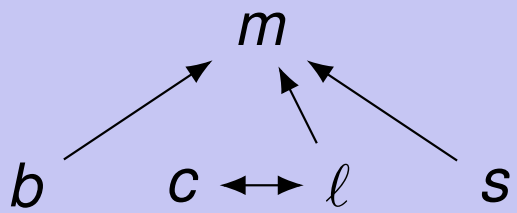

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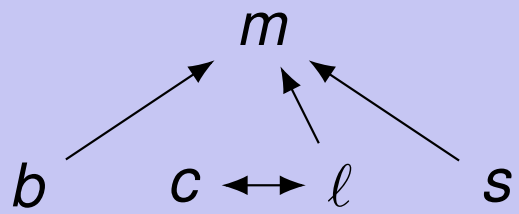

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« let multi f x = ... » $\rightsquigarrow m \blacktriangleleft c$

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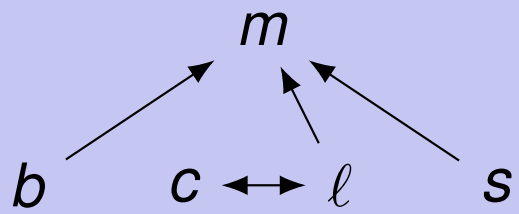

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Error

Q: What are the rules?

Other relations

- Accessibility: "λ_1 can *read* in λ_2 memory"
- Propagation: prevailing effect among types
- Weakening: type generalization under constraints
- Serialisation: safety of communicating τ_π to locality λ

One example of rule (**let** $x = e_1$ **in** e_2)

$$\text{LET IN} \quad \frac{\begin{array}{l}\Lambda, \Gamma \vdash e_1 : \tau^1_{\pi_1} / \varepsilon_1[c_1] \\ \Lambda, \Gamma; x : \mathbf{Weak}(\tau^1_{\pi_1}, \varepsilon_1, \Gamma) \vdash e_2 : \tau^2_{\pi_2} / \varepsilon_2[c_2] \\ c_3 \equiv [\Psi = \mathbf{Propgt}(\varepsilon_1, \varepsilon_2), c_1, c_2]\end{array}}{\Lambda, \Gamma \vdash \mathbf{let}\ x = e_1\ \mathbf{in}\ e_2 : \tau^2_{\pi_2} / \Psi[c_3]}$$

Formal properties

Operational semantics

- Big step semantics $\Downarrow_p^{\mathcal{L}}$
- Big step semantics for diverging terms
- Programs that *"do not go wrong"*, $e \Rightarrow_{safe}$:

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- Let e be an expression (program),
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- BSML for BSP;
- MULTI-ML for MULTI-BSP
- A type system (with constraints and effects) to forbid erronous MULTI-ML codes
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Perspectives (Ongoing/Future Work)

- Implementation for a full language
- Static and automatic analysis for cost prediction
- Application to bigger examples

Merci !