Programming in Multi-BSP: Multi-ML and its typing system

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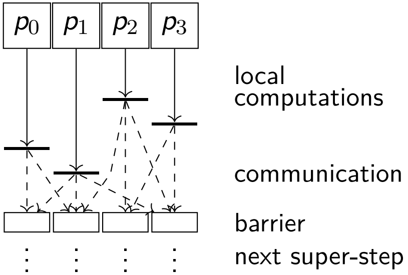
Bulk Synchronous Parallelism

A BSP computer:

- **p** pairs CPU/memory
- Communication network
- Synchronization unit



Bulk **S**ynchronous **P**arallelism

A BSP computer:

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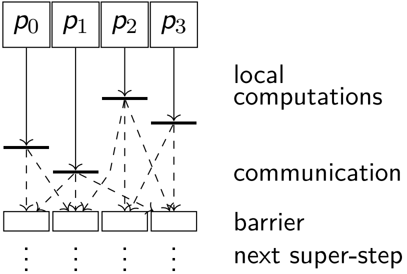
Properties:

- Super-steps execution
- Confluent
- Deadlock-free
- Predictable performances



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Bulk Synchronous ML

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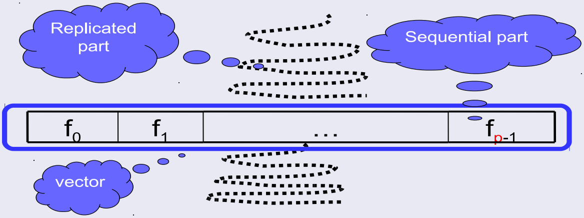
Main idea

Parallel data structure ⇒ Vector:



Asynchronous primitives

BSML primitives

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Synchronous primitives

- `proj` : $\langle x_0, \ldots, x_{\mathbf{p}-1}\rangle \mapsto (\textbf{fun } i \rightarrow x_i)$
- `put` : $\langle f_0, \ldots, f_{\mathbf{p}-1}\rangle \mapsto \langle(\textbf{fun } i \rightarrow f_i\ 0), \ldots, (\textbf{fun } i \rightarrow f_i\ (\mathbf{p}-1))\rangle$

Code example

For a BSP machine with 3 processors:

```
# let vec = << "Hello" >>;;
val vec : string par = <"Hello", "Hello", "Hello">

# let vec2 = << $vec$^(string_of_int $pid$) >>;;
val vec2 : string par = <"Hello0", "Hello1", "Hello2">

# let totex v = List.map (proj v) procs;;
val totex : 'a par -> 'a list = <fun>

# totex vec2;;
- : string list = ["Hello0"; "Hello1"; "Hello2"]
```

The MULTI-BSP model

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1. A tree structure with nested components
2. Where nodes have a storage capacity
3. And leaves are processors

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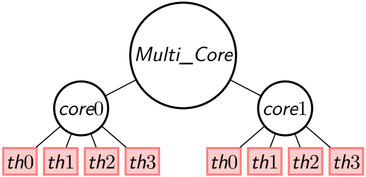

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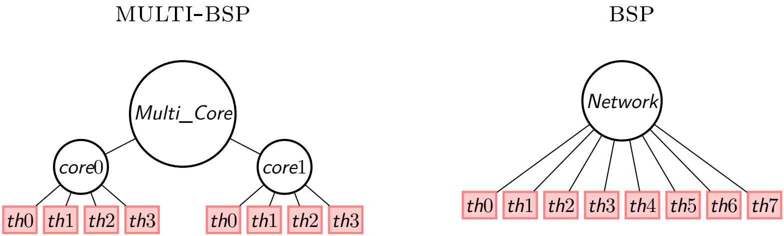
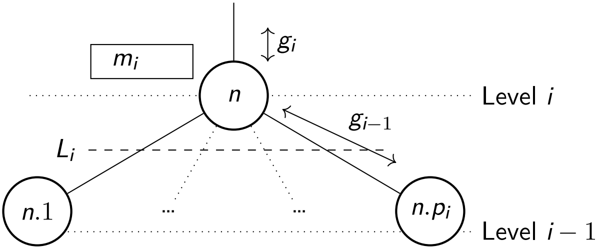


Execution model

A level i superstep is:



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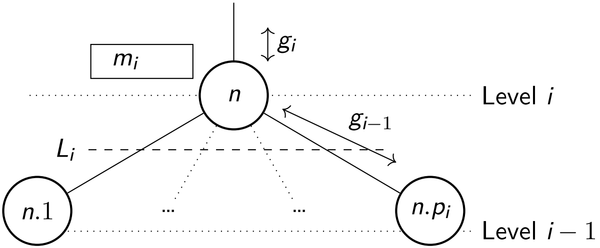

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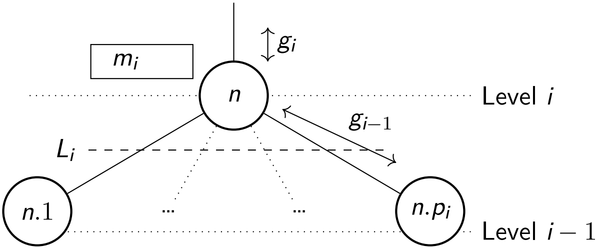

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Execution model

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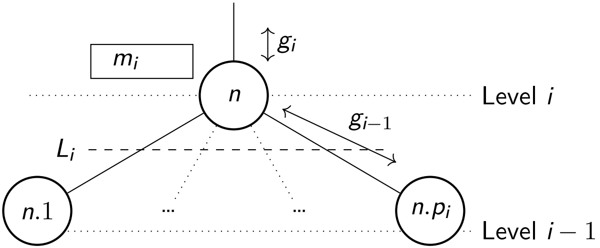
- Exchanges informations with the m_i memory
- Synchronises



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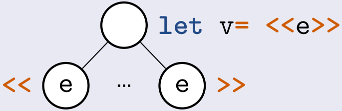

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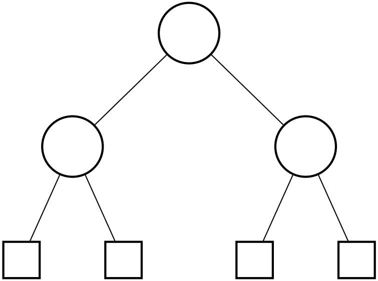

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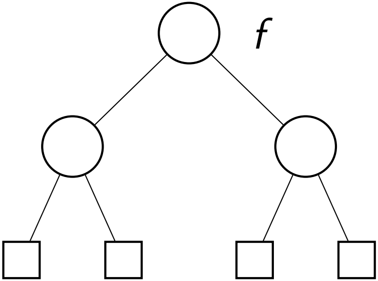

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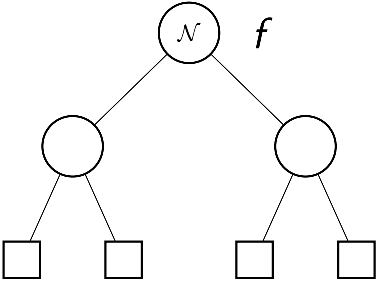

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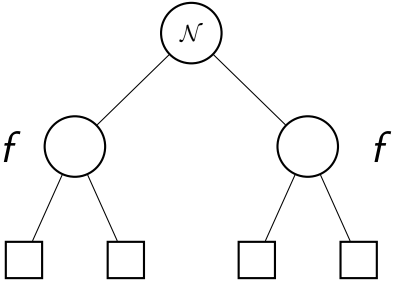

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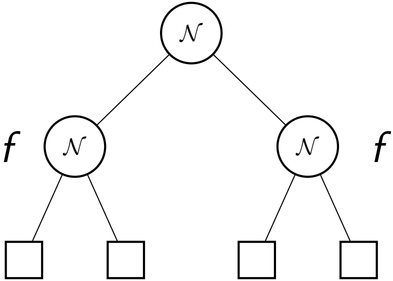

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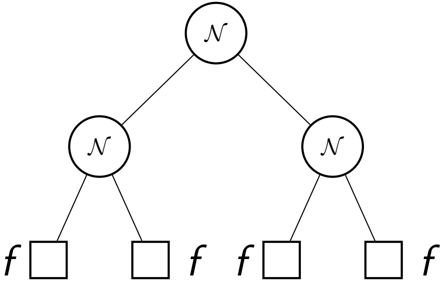

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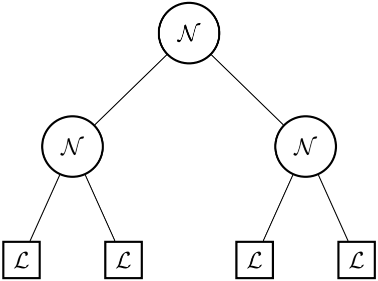

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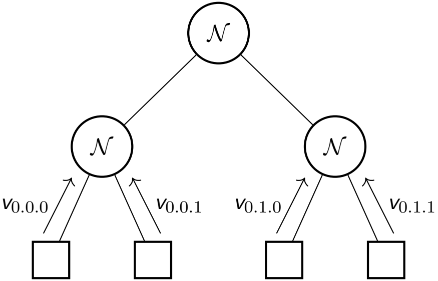

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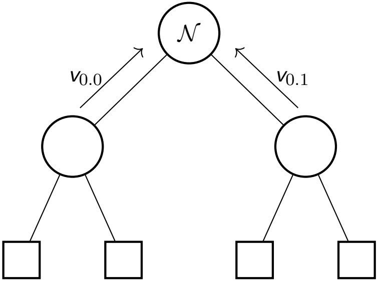

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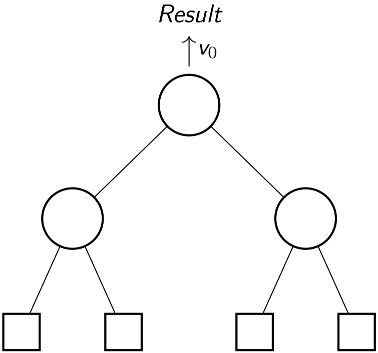

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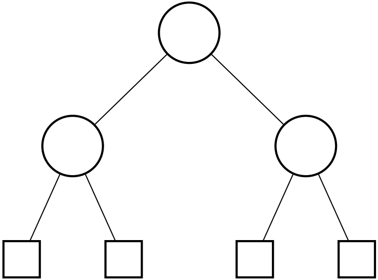

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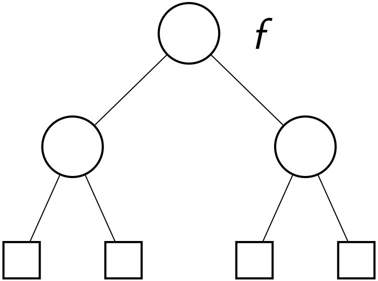

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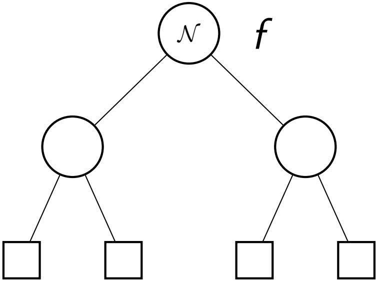

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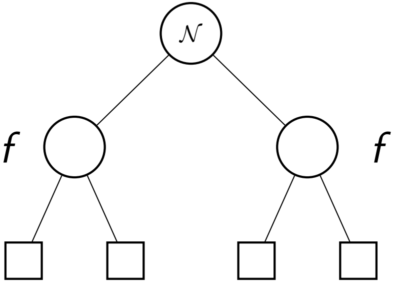

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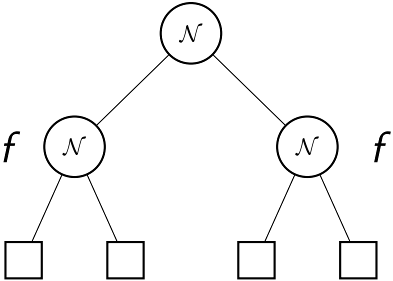

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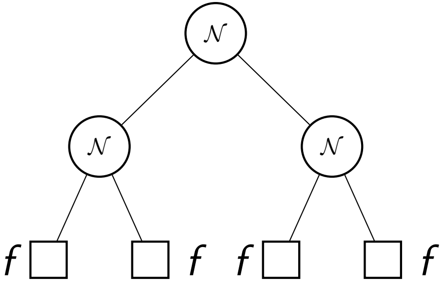

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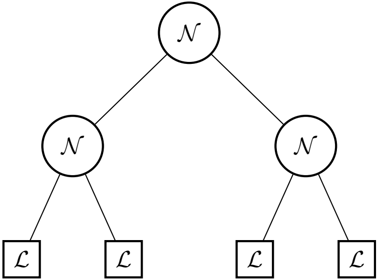

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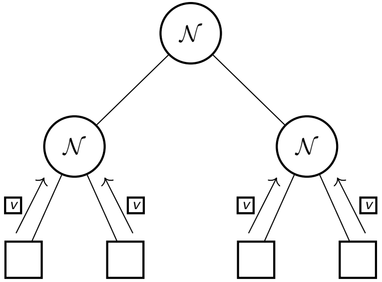

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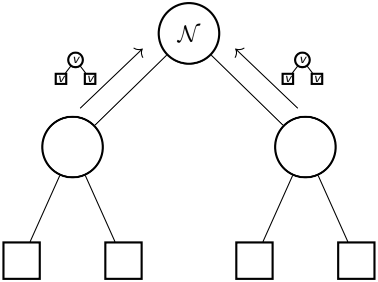

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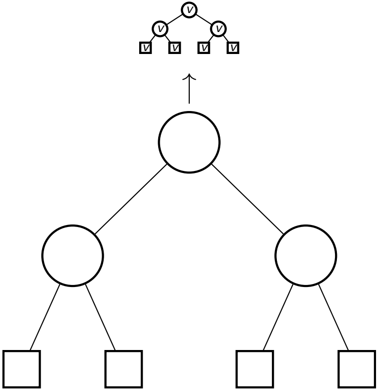

Primitives

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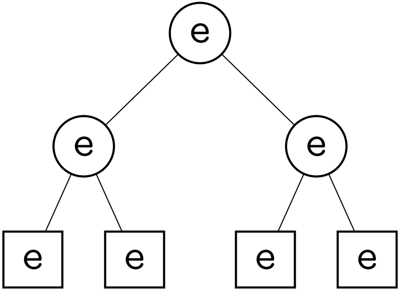

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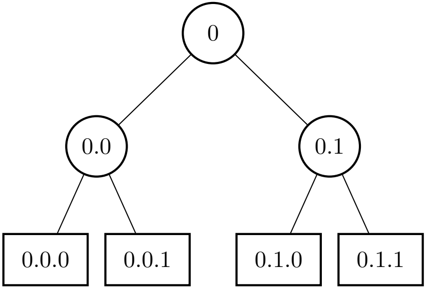

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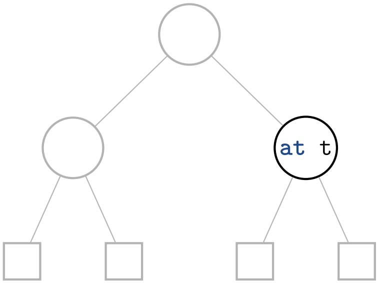

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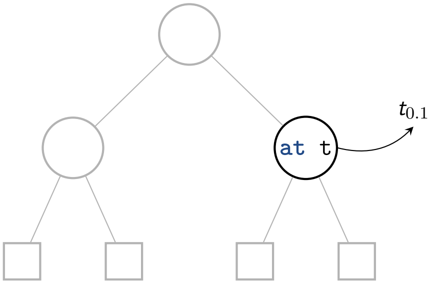

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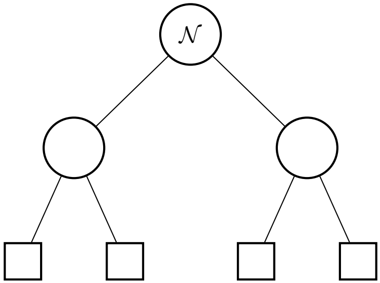

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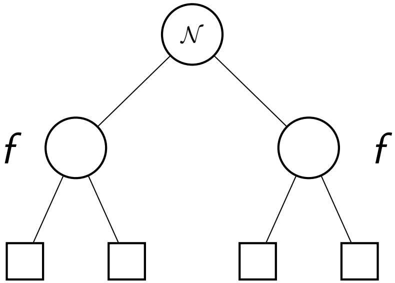

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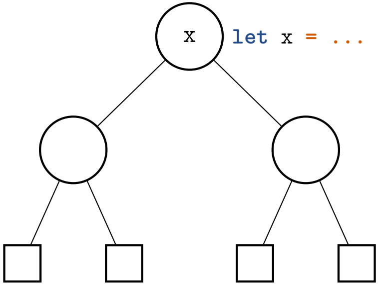

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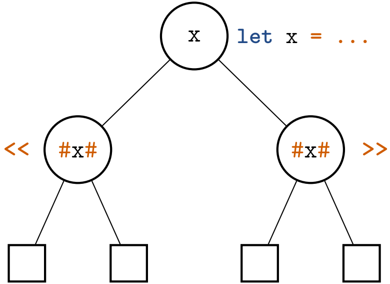

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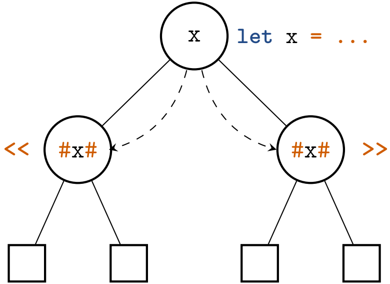

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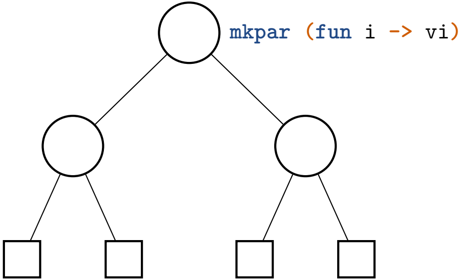

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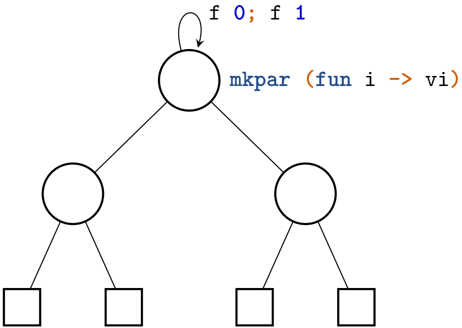

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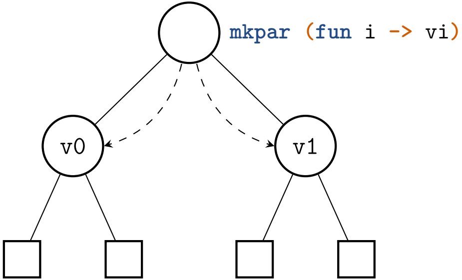
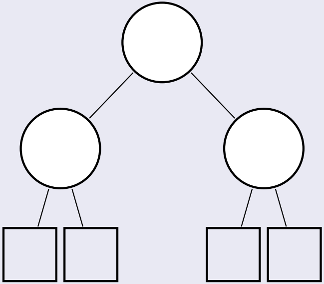


Code example

Keep the intermediate results of the sum



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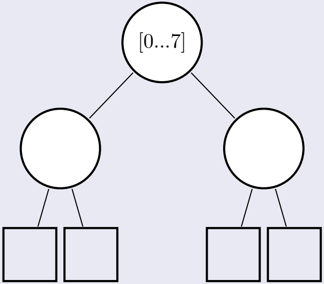
      let rc = << sum_list $v$ >> in
      let s = sumSeq (flatten << at $rc$ >>)
      in (rc,s)
   where leaf =

      sumSeq l
```

Code example

Keep the intermediate results of the sum

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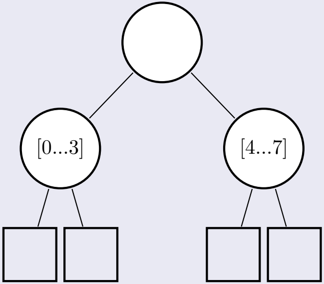


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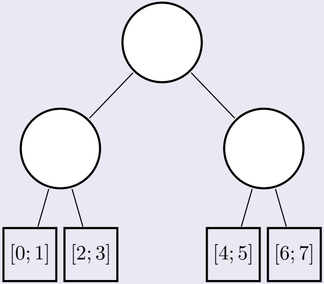


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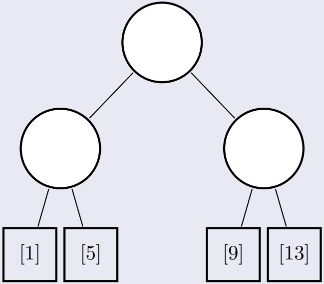


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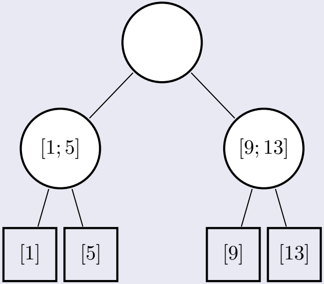


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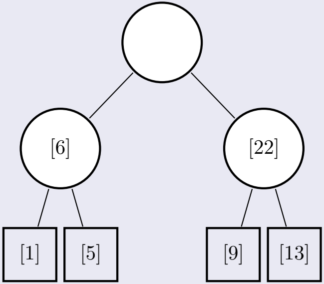


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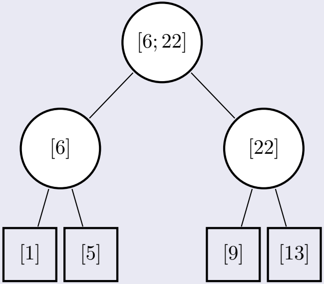


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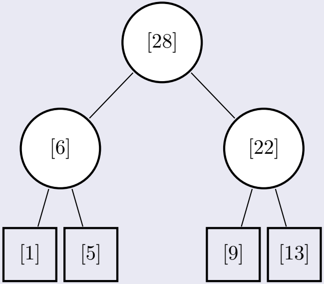


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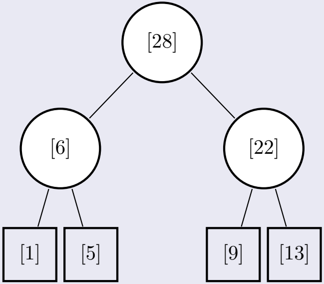


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Implementation

Run on multi-core clusters using MPI.

Table of Contents

Parallel program safety

- Replicated coherency

Replicated coherency

```
if random_bool () then
  proj v
else
  ...
```

Typing system

Parallel program safety

- Replicated coherency
- Level (memory) compatibility

Level(memory) compatibility

```
<< let multi f x = ... >>
```

Typing system

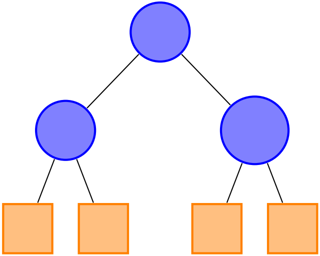
Parallel program safety

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

Parallel structure imbrication

```
let v = << ... >> in << v >>
```

Type localities



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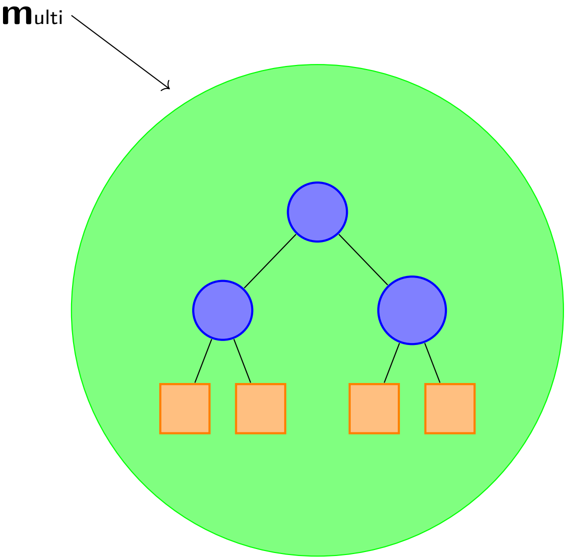

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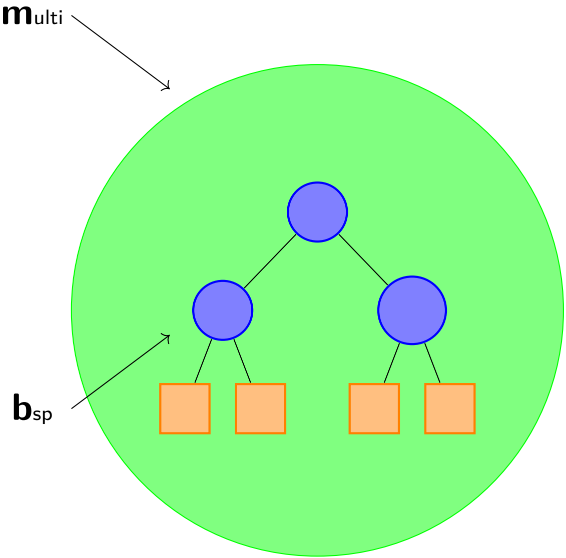

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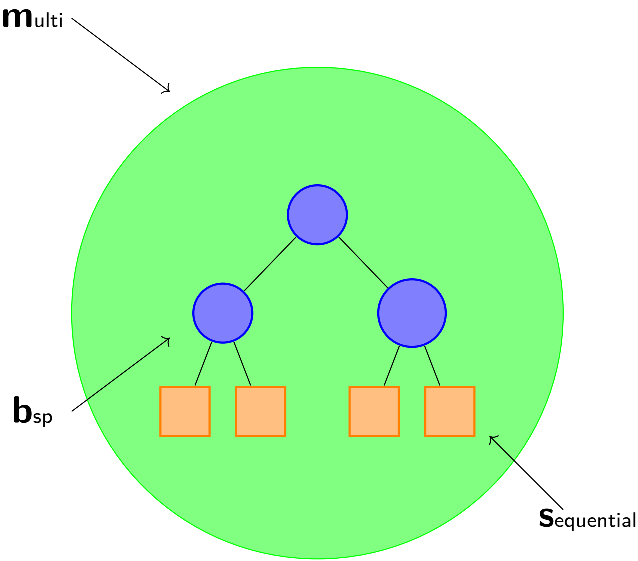

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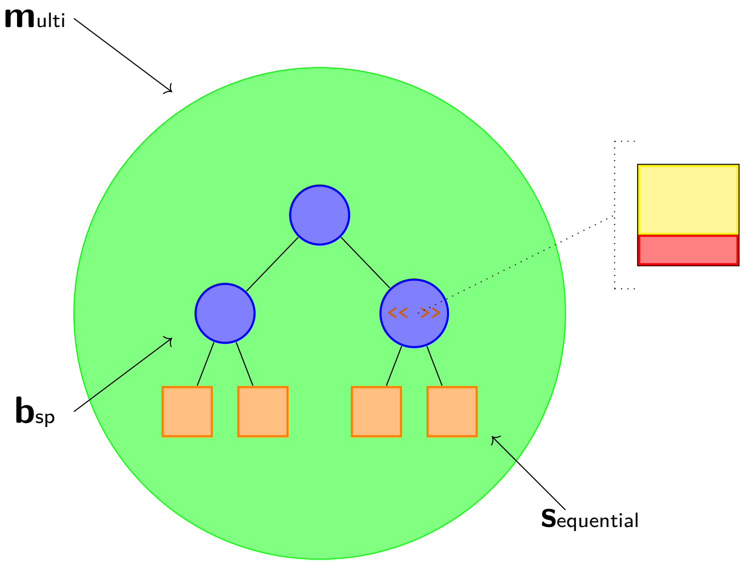

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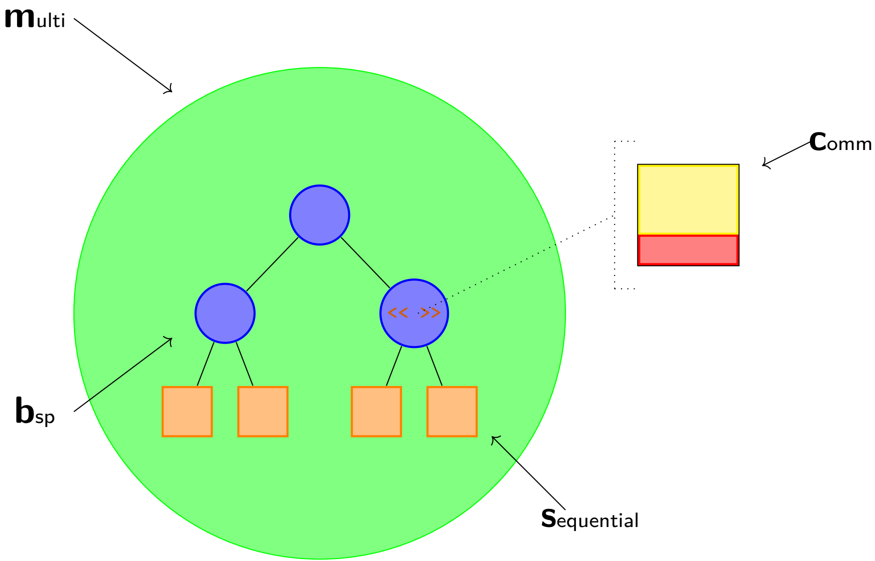

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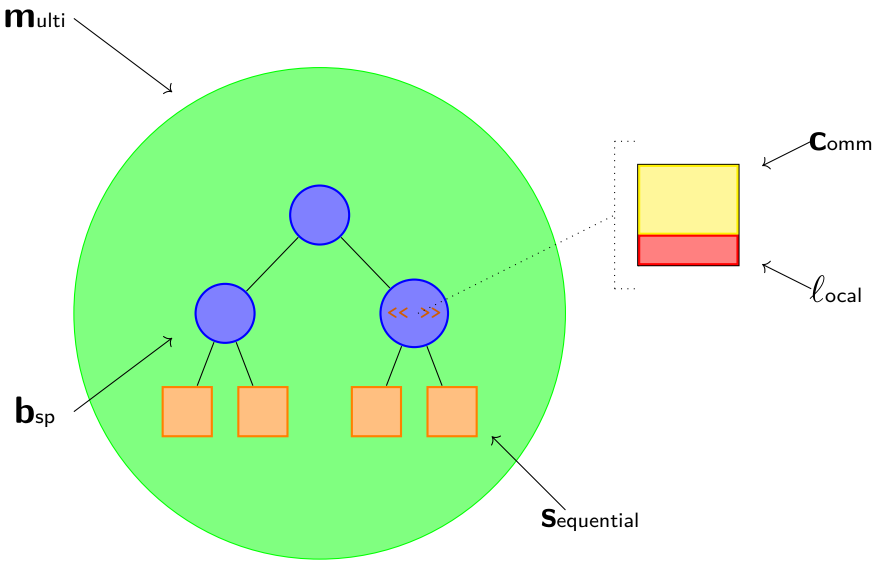
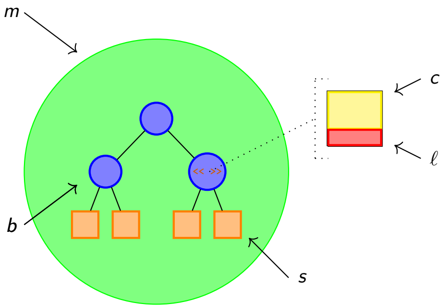


Type annotations



Type annotation

τ ::=

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

$\pi ::= m \mid b \mid c \mid l \mid s$

Type annotation

Latent effect

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

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

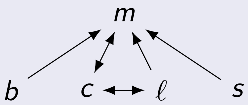
A BSP function

```
#let f = fun x ->
   let v = << ... >> in 1
-: val f : ('a_`z -(b)-> int_b)_m
```

$$f : ({'a}_{`z} \xrightarrow{b} int_b)_m$$

Accessibility: $\lhd$

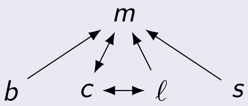
$$\begin{array}{rcl} m, c & \lhd & m \\ m, b & \lhd & b \\ m, l, c & \lhd & l \\ m, l, c & \lhd & c \\ m, s & \lhd & s \end{array}$$



$\lambda_2 \lhd \lambda_1$: « λ_1 *can read in* λ_2 *memory.* »

Accessibility: $\lhd$

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



$$\lambda_2 \lhd \lambda_1 : \text{« } \lambda_1 \textit{ can read in } \lambda_2 \textit{ memory. »}$$

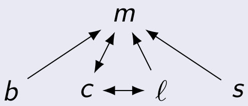
Example:

$$f : ('a_z \xrightarrow{b} int_b)_m$$
$$f\ 1 \rightsquigarrow b \lhd m$$

Accessibility

Accessibility: $\lhd$

$$
\begin{aligned}
m, c &\lhd m \\
m, b &\lhd b \\
m, l, c &\lhd l \\
m, l, c &\lhd c \\
m, s &\lhd s
\end{aligned}
$$



$$\lambda_2 \lhd \lambda_1 : \text{« } \lambda_1 \textit{ can read in } \lambda_2 \textit{ memory. } \text{»}$$

Example:

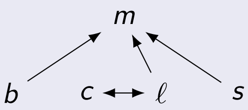
$$f : ('a_z \xrightarrow{b} int_b)_m$$

$$f\ 1 \rightsquigarrow b \lhd m$$

Error

Definability: ◀

s, b, m	◀	m
b	◀	b
l, c	◀	c
l, c	◀	l
s	◀	s

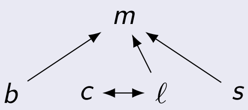


λ_1 ◀ λ_2 : « λ_1 *can be defined in* λ_2 *memory.* »

Definability

Definability: $\blacktriangleleft$

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



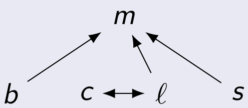
$\lambda_1 \blacktriangleleft \lambda_2$: « λ_1 *can be defined in* λ_2 *memory.* »

Example:

$$<< let\ multi\ f\ x\ =\ ...\ >> \rightsquigarrow m \blacktriangleleft b$$

Definability: ◀

s, b, m	◀	m
b	◀	b
l, c	◀	c
l, c	◀	l
s	◀	s



$\lambda_1 \blacktriangleleft \lambda_2$: « λ_1 *can be defined in* λ_2 *memory.* »

Example:

$<<$ *let multi f x* $=$ ... $>> \rightsquigarrow m \blacktriangleleft b$

Error

Propagation: $Propgt(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\perp$
c	*m*	*b*	*l*	*c*	$\perp$
s	*m*	*b*	$\perp$	$\perp$	*s*

Propagation: $Propgt(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\perp$
c	*m*	*b*	*l*	*c*	$\perp$
s	*m*	*b*	$\perp$	$\perp$	*s*

Constraint generation

$$\llbracket\ e_1\ e_2 : \tau_\Lambda / \Psi\ \rrbracket^\Lambda =$$

Propagation: $Propgt(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\perp$
c	*m*	*b*	*l*	*c*	$\perp$
s	*m*	*b*	$\perp$	$\perp$	*s*

Constraint generation

$$\llbracket\ e_1\ e_2 : \tau_\Lambda/\Psi\ \rrbracket^\Lambda = \llbracket\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta/\varepsilon'\ \rrbracket^\Lambda$$

Propagation: $Propgt(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\perp$
c	*m*	*b*	*l*	*c*	$\perp$
s	*m*	*b*	$\perp$	$\perp$	*s*

Constraint generation

$$\llbracket\ e_1\ e_2 : \tau_\Lambda/\Psi\ \rrbracket^\Lambda = \llbracket\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta/\varepsilon'\ \rrbracket^\Lambda \wedge \llbracket\ e_2 : \alpha_{\pi''}/\varepsilon''\ \rrbracket^\Lambda$$

Propagation: $Propgt(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\perp$
c	*m*	*b*	*l*	*c*	$\perp$
s	*m*	*b*	$\perp$	$\perp$	*s*

Constraint generation

$\llbracket\ e_1\ e_2 : \tau_\Lambda / \Psi\ \rrbracket^\Lambda = \llbracket\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta / \varepsilon'\ \rrbracket^\Lambda \wedge \llbracket\ e_2 : \alpha_{\pi''} / \varepsilon''\ \rrbracket^\Lambda$
$\wedge \pi'' \lhd \pi$

Propagation: *Propgt*$(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\bot$
c	*m*	*b*	*l*	*c*	$\bot$
s	*m*	*b*	$\bot$	$\bot$	*s*

Constraint generation

$$[\![\ e_1\ e_2 : \tau_\Lambda / \Psi\ ]\!]^\Lambda = [\![\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta / \varepsilon'\ ]\!]^\Lambda \wedge [\![\ e_2 : \alpha_{\pi''} / \varepsilon''\ ]\!]^\Lambda$$
$$\wedge \pi'' \lhd \pi \quad \wedge \varepsilon \lhd \Lambda$$

Propagation: $\mathit{Propgt}(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\bot$
c	*m*	*b*	*l*	*c*	$\bot$
s	*m*	*b*	$\bot$	$\bot$	*s*

Constraint generation

$$[\![\ e_1\ e_2 : \tau_\Lambda/\Psi\ ]\!]^\Lambda = [\![\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta/\varepsilon'\ ]\!]^\Lambda \wedge [\![\ e_2 : \alpha_{\pi''}/\varepsilon''\ ]\!]^\Lambda$$
$$\wedge \pi'' \lhd \pi \quad \wedge \varepsilon \lhd \Lambda \quad \wedge \varepsilon \blacktriangleleft \Lambda$$

Propagation: *Propgt*$(\varepsilon, \varepsilon')$

This relation returns the prevailing effect amongst ε and ε'.

Propgt	*m*	*b*	*l*	*c*	*s*
m	*m*	*m*	*m*	*m*	*m*
b	*m*	*b*	*b*	*b*	*b*
l	*m*	*b*	*l*	*l*	$\bot$
c	*m*	*b*	*l*	*c*	$\bot$
s	*m*	*b*	$\bot$	$\bot$	*s*

Constraint generation

$$[\![\ e_1\ e_2 : \tau_\Lambda/\Psi\ ]\!]^\Lambda = [\![\ e_1 : (\alpha_\pi \xrightarrow{\varepsilon} \tau_{\pi'})_\delta/\varepsilon'\ ]\!]^\Lambda \wedge [\![\ e_2 : \alpha_{\pi''}/\varepsilon''\ ]\!]^\Lambda$$
$$\wedge \pi'' \lhd \pi \quad \wedge \varepsilon \lhd \Lambda \quad \wedge \varepsilon \blacktriangleleft \Lambda \quad \wedge \Psi = \mathit{Propgt}(\varepsilon, \varepsilon', \varepsilon'')$$

Serialisation: $Seria_{\Lambda}(\tau_\pi)$

Is it safe to communicate τ_π to locality Λ ?

$$\begin{array}{lcl}
Seria_\alpha(\tau_\pi) & = & \begin{cases} \tau_\pi, & \mathit{if}\ \pi \lhd \alpha \end{cases} \\
Seria_\alpha(\texttt{Base}_\pi) & = & \texttt{Base}_\pi\ \ \mathit{if}\ \texttt{Base} = \texttt{int}, \texttt{Bool}, \ldots \\
Seria_\alpha(\texttt{Base}_\pi) & = & \texttt{Fail}\ \ \mathit{if}\ \texttt{Base} = \texttt{i/o}, \ldots \\
Seria_\alpha(\tau_\pi\ \texttt{par}_b) & = & \texttt{Fail} \\
Seria_\alpha(\texttt{tree}_\pi) & = & \texttt{Fail} \\
Seria_\alpha(_ \xrightarrow{l} _) & = & \texttt{Fail} \\
\ldots & & \\
Seria_\alpha((\tau^1_\pi \xrightarrow{\varepsilon} \tau^2_{\pi'})_\delta) & = & \begin{cases} (\tau'^1_\pi \xrightarrow{\varepsilon} \tau'^2_{\pi'})_\delta, & \mathit{if}\ \varepsilon \# m, b, s, l \\ & \mathit{and}\ \tau'^1_\pi = Seria_\alpha(\tau^1_\pi) \\ & \mathit{and}\ \tau'^2_{\pi'} = Seria_\alpha(\tau^2_{\pi'}) \end{cases}
\end{array}$$

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- Big-steps formal semantics (confuent)
- Type system (safety and inference using HM(X) like)

Current/Future work

- Full implementation (record, tuples, ...)
- Variants
- Modules and other OCAML features
- Error tracking

Merci !

Any questions ?