The hierarchy of analytic semantics of weakly consistent parallelism

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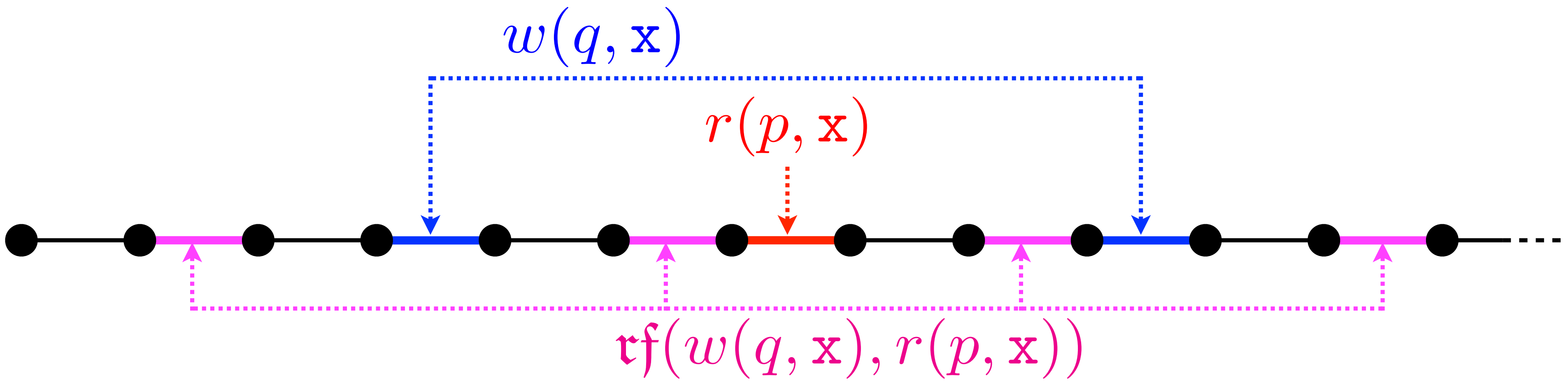
Analytic semantics

Weak consistency models (WCM)

- Sequential consistency:
  reads $r(p, \mathrm{x})$ are *implicitly coordinated* with writes $w(q, \mathrm{x})$

- WCM:
  No implicit coordination (depends on architecture, program dependencies, and explicit fences)



Analytic semantic specification

- Anarchic semantics:

  describes computations, no constraints on communications

- cat specification (Jade Alglave & Luc Maranget):

  imposes architecture-dependent communication constraints

- Hierarchy of anarchic semantics:

  many different styles to describe the same computations (e.g. stateless/stateful, interleaved versus true parallelism)

Example: load buffer (LB)

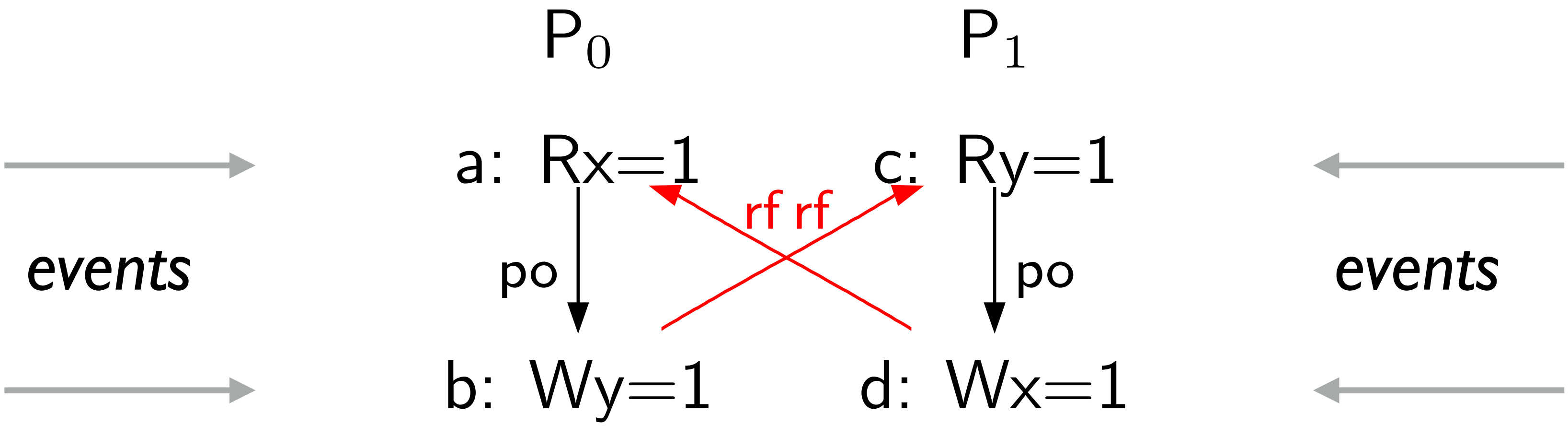
- Program:

```
{ x = 0; y = 0; }
P0          | P1        ;
r[] r1 x    | r[] r2 y  ;
w[] y 1     | w[] x   1 ;
exists(0:r1=1 /\ 1:r2=1)
```

- Example of execution trace $t \in \mathcal{S}^{\perp}[\![\mathtt{P}]\!]$:

$$t = w(\text{start}, \mathrm{x}, 0)\ w(\text{start}, \mathrm{y}, 0)\ r(\mathtt{P0}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\mathtt{P0}, \mathrm{x}, 1)])\ w(\mathtt{P0}, \mathrm{y}, 1)\ r(\mathtt{P1}, \mathrm{y}, 1)\ w(\mathtt{P1}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\mathtt{P1}, \mathrm{y}, 1)]\ r(\text{finish}, \mathrm{x})\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\text{finish}, \mathrm{x}, 1)]\ r(\text{finish}, \mathrm{y}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\text{finish}, \mathrm{y}, 1)]$$

- Abstraction to cat *candidate execution* $\alpha_{\Xi}(t)$:



P_0

P_1

events

a: Rx=1

c: Ry=1

rf rf

po

po

b: Wy=1

d: Wx=1

events

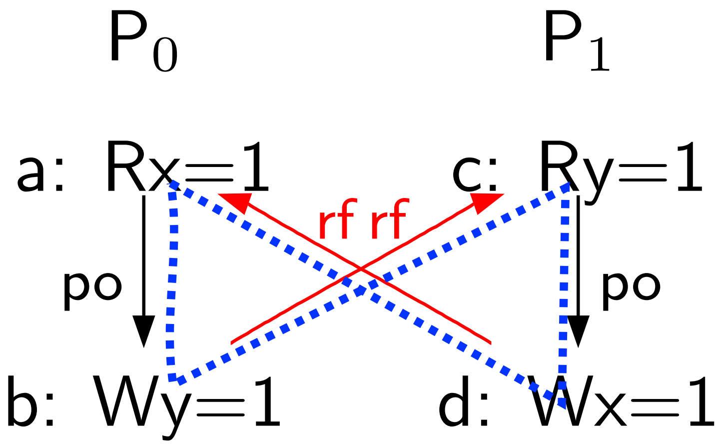
Example: load buffer (LB), cont'd

- cat specification:

```
acyclic (po | rf)+
```

The cat semantics rejects this execution $\alpha_{\Xi}(t)$:

$$🐱[\![\texttt{cat}]\!]\,(\alpha_{\Xi}(t)) \;=\; \textbf{false}$$



- The herd7 tool: `virginia.cs.ucl.ac.uk/herd/`

The WCM semantics

- Abstraction to a candidate execution:

$$\alpha_{\Xi}(t) \triangleq \langle \alpha_{e}(t),\ \alpha_{po}(t),\ \alpha_{rf}(t),\ \alpha_{iw}(t),\ \alpha_{fw}(t)\rangle$$

$$\alpha_{\Xi}(\mathsf{S}) \triangleq \{\langle t,\ \alpha_{\Xi}(t)\rangle \mid t \in \mathsf{S}\}$$

- The cat semantics:

$$\alpha_{\text{🐱}}[\![\texttt{cat}]\!](\mathsf{S}) \triangleq \{t \mid \langle t,\ \Xi\rangle \in \mathsf{S} \wedge \text{🐱}[\![\texttt{cat}]\!](\Xi)\}$$

- The WCM semantics:

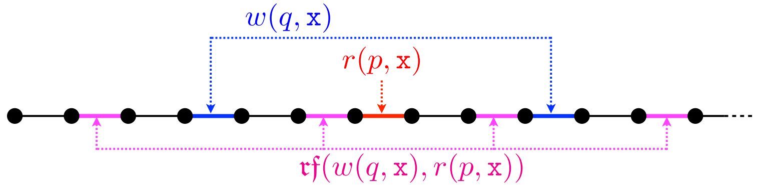
$$\alpha_{\text{🐱}}[\![\texttt{cat}]\!] \circ \alpha_{\Xi}(\mathsf{S}[\![\mathrm{P}]\!])$$

GC: $\langle \wp(\mathfrak{E}^{+\infty}),\ \subseteq\rangle \mathrel{\underset{\alpha_{\Xi}}{\overset{\gamma_{\Xi}}{\leftrightarrows}}} \langle \wp(\mathfrak{E}^{+\infty} \times \Xi), \subseteq\rangle \mathrel{\underset{\alpha_{\text{🐱}}[\![\texttt{cat}]\!]}{\overset{\gamma_{\text{🐱}}[\![\texttt{cat}]\!]}{\leftrightarrows}}} \langle \wp(\mathfrak{E}^{+\infty}),\ \subseteq\rangle$

Definition of the anarchic semantics

Axiomatic parameterized definition of the anarchic semantics

- The semantics $S^{\perp}[\![\mathrm{P}]\!]$ is a finite/infinite sequence of *interleaved* events of processes satisfying well-formedness conditions.
- Events:
  - local computations and tests on registers
  - start writing a shared variable $w(q, \mathtt{x})$
  - start reading of shared variable $r(p, \mathtt{x})$
  - communication event $\mathfrak{rf}(w(q, \mathtt{x}), r(p, \mathtt{x}))$



Axiomatic parameterized definition of the anarchic semantics

- Examples of language independent well-formedness conditions of a semantics *S*:
  - uniqueness of events

$$\forall t \in S \,.\, \forall t_1, t_2 \in \mathfrak{E}^*, t_3 \in \mathfrak{E}^{*\infty} \,.\, \forall e, e' \in \mathfrak{E} \,.\, (t = t_1\, e\, t_2\, e'\, t_3) \Longrightarrow (e \neq e') \,. \qquad (\mathsf{Wf}_1(S))$$

  - traces start with an initialization of the shared variables $(\mathsf{Wf}_2(S))$

$$\begin{aligned} t \;=\; & w(\textsf{start}, \mathrm{x}, 0)\; w(\textsf{start}, \mathrm{y}, 0)\; r(\mathtt{P0}, \mathrm{x}, 1)\; \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\mathtt{P0}, \mathrm{x}, 1)])\; w(\mathtt{P0}, \mathrm{y}, 1)\; r(\mathtt{P1}, \mathrm{y}, 1) \\ & w(\mathtt{P1}, \mathrm{x}, 1)\; \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\mathtt{P1}, \mathrm{y}, 1)]\; r(\textsf{finish}, \mathrm{x})\; \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\textsf{finish}, \mathrm{x}, 1)] \\ & r(\textsf{finish}, \mathrm{y}, 1)\; \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\textsf{finish}, \mathrm{y}, 1)] \end{aligned}$$

Axiomatic parameterized definition of the anarchic semantics

- Examples of language independent well-formedness conditions of a semantics S:
  - finite traces are maximal

$$\forall t \in S \cap \mathfrak{E}^{+} \;.\; \nexists t' \in \mathfrak{E}^{+\infty} \;.\; t\, t' \in S \;. \qquad (\mathsf{Wf}_3(S))$$

  - the final value of shared variables in finite traces is known thanks to a final read $(\mathsf{Wf}_4(S))$

$$\begin{aligned} t \;=\; & w(\text{start}, \mathrm{x}, 0)\; w(\text{start}, \mathrm{y}, 0)\; r(\mathtt{P0}, \mathrm{x}, 1)\; \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\mathtt{P0}, \mathrm{x}, 1)])\; w(\mathtt{P0}, \mathrm{y}, 1)\; r(\mathtt{P1}, \mathrm{y}, 1) \\ & w(\mathtt{P1}, \mathrm{x}, 1)\; \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\mathtt{P1}, \mathrm{y}, 1)]\; r(\text{finish}, \mathrm{x})\; \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\text{finish}, \mathrm{x}, 1)] \\ & r(\text{finish}, \mathrm{y}, 1)\; \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\text{finish}, \mathrm{y}, 1)] \end{aligned}$$

Axiomatic parameterized definition of the anarchic semantics

- Examples of language independent well-formedness conditions of a semantics *S*:
  - read events must be satisfied by a unique communication event

$$\forall t \in \mathsf{S} \,.\, \forall t_1 \in \mathfrak{E}^*, t_2 \in \mathfrak{E}^{*\infty} \,.\, (t = t_1\, r(p, \mathrm{x})\, t_2) \Longrightarrow \qquad (\mathsf{Wf}_5(\mathsf{S}))$$

$$(\exists t_3 \in \mathfrak{E}^*, t_4 \in \mathfrak{E}^{*\infty} \,.\, t = t_3\, \mathfrak{rf}[w(q, \mathrm{x}), r(p, \mathrm{x})]\, t_4) \,.$$

$$\forall t \in \mathsf{S} \,.\, \forall t_1, t_2 \in \mathfrak{E}^*, t_3 \in \mathfrak{E}^{*\infty} \,. \qquad (\mathsf{Wf}_6(\mathsf{S}))$$

$$(t \neq t_1\, \mathfrak{rf}[w(q, \mathrm{x}), r(p, \mathrm{x})]\, t_2\, \mathfrak{rf}[w'(q', \mathrm{x}), r(p, \mathrm{x})]\, t_3) \,.$$

Axiomatic parameterized definition of the anarchic semantics

- Examples of language independent well-formedness conditions of a semantics *S*:
  - communications cannot be spontaneous (must be originated by a read *and* a write)

$$\forall t \in \mathsf{S} \,.\, \forall t_1 \in \mathfrak{E}^{*}, t_2 \in \mathfrak{E}^{*\infty} \,.\, (t = t_1\, \mathfrak{rf}[w(q,\mathtt{x}), r(p,\mathtt{x})]\, t_2) \Longrightarrow \qquad (\mathsf{Wf}_7(\mathsf{S}))$$
$$(\exists t_3 \in \mathfrak{E}^{*}, t_4 \in \mathfrak{E}^{*\infty} \,.\, t = t_3 w(q,\mathtt{x}) t_4 \wedge \exists t_5 \in \mathfrak{E}^{*}, t_6 \in \mathfrak{E}^{*\infty} \,.\, t = t_5 r(p,\mathtt{x}) t_6)\ .$$

Axiomatic parameterized definition of the anarchic semantics

- The language :

  process

  - Programs : *initialisation* $[\![\mathrm{P}_1 \| \ldots \| \mathrm{P}_n]\!]$ *finalisation*
  - Actions (labelled $\ell \in \mathbb{L}(p)$) :

$a ::= m$	imperative actions	marker
$\mid$ `r := `e		assignment
$\mid$ `r := x`		read of shared variable `x`
$\mid$ `x := `e		write of shared variable `x`
$\mid$ $b \mid \neg b$	conditional actions	test

  - Next action : $\mathsf{next}(p, \ell)$ $\mathsf{nextt}(p, \ell)$ $\mathsf{nextf}(p, \ell)$

  for tests

Axiomatic parameterized definition of the anarchic semantics

- Example of language-dependent well-formedness condition: computation (*markers*: skip, fence, begin/end of rmw)

Any process p

Any point k in trace

Any label ℓ of p

marker event by process p in trace τ

$$\begin{aligned}&\forall p \in \mathbb{P}\mathbb{i} \;.\; \forall k \in [1, 1 + |\tau|[\;.\; \forall \ell \in \mathbb{L}(p) \;.\\ &\quad (\exists \theta \in \mathfrak{P}(p) \;.\; \overline{\tau}_k = \mathfrak{m}(\langle p,\, \ell,\, m,\, \theta\rangle))\\ &\quad\quad \Longrightarrow (\ell \in \mathsf{N}^p(\tau, k) \wedge \mathsf{action}(p, \ell) = m) \;.\end{aligned} \qquad (\mathsf{Wf}_{21}(\tau))$$

(unique) event stamp θ

control of process p is at label ℓ

action of process p is at label ℓ is the marker action m

Axiomatic parameterized definition of the anarchic semantics

- Example of language-dependent well-formedness condition: computation (local variable assignment)

register assignment event by process p in trace τ

(unique) event stamp θ

$$\forall p \in \mathbb{P}\mathbb{i} \,.\, \forall k \in \,]1, 1+|\tau|[\, .\, \forall \ell \in \mathbb{L}(p) \,.\, \forall v \in \mathcal{D} \,. \qquad (\mathsf{Wf}_{22}(\tau))$$
$$(\exists \theta \in \mathfrak{P}(p) \,.\, \overline{\tau}_k = \mathfrak{a}(\langle p,\, \ell,\, \mathtt{r} \mathrel{\mathtt{:=}} e,\, \theta\rangle, v))$$
$$\Longrightarrow (\ell \in \mathsf{N}^p(\tau, k) \wedge \mathsf{action}(p, \ell) = \mathtt{r} \mathrel{\mathtt{:=}} e \wedge v = \mathsf{E}^p[\![e]\!](\tau, k-1)) \,.$$

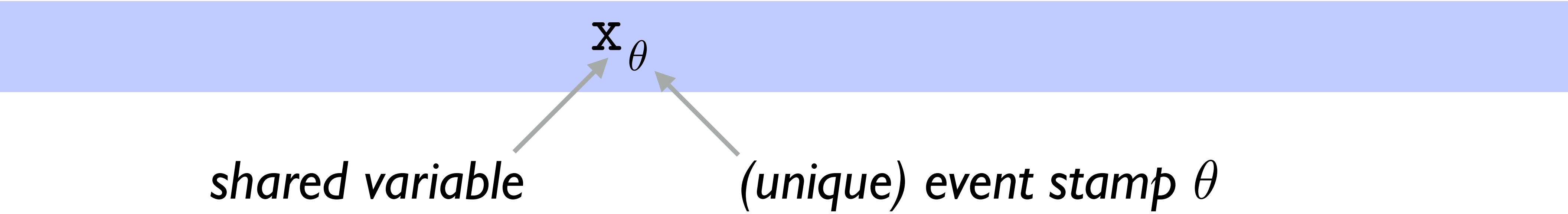
control of process p is at label ℓ

action of process p is at label ℓ is a register assignment

value v of e is evaluated by past-travel

Media variables

- With WCM there is no notion of *“the current value of shared variable* `x`”
- At a given time each process may read a *different value* of the shared variable `x` (maybe guessed or unknown since a read may read from a future write)
- We use *media variables* (to record the values communicated between a write and read, whether the two accesses are on the same process or not)



$\mathtt{x}_{\theta}$

shared variable

(unique) event stamp θ

Axiomatic parameterized definition of the anarchic semantics

- Example: communication
  - a read event is initiated by a read action:

read event by process p in trace τ

unique media variable

$$\forall p \in \mathbb{P}\mathbb{i} \;.\; \forall k \in \,]1, 1+|\tau|[\;.\; \forall \ell \in \mathbb{L}(p) \;. \qquad (\mathsf{Wf}_{23}(\tau))$$
$$(\exists \theta \in \mathfrak{P}(p) \;.\; (\overline{\tau}_k = \mathfrak{r}(\langle p,\ \ell,\ \mathtt{r}\ \mathtt{:=}\ \mathtt{x},\ \theta\rangle, \mathtt{x}_\theta)))$$
$$\Longrightarrow (\ell \in \mathsf{N}^p(\tau, k) \wedge \mathsf{action}(p, \ell) = \mathtt{r}\ \mathtt{:=}\ \mathtt{x}) \;.$$

- a read must read-from ($\mathfrak{rf}$) a write (weak fairness):

$$\forall p \in \mathbb{P}\mathbb{i} \;.\; \forall i \in \,]1, 1+|\tau|[\;.\; \forall r \in \mathfrak{Rf}(p) \;. \qquad (\mathsf{Wf}_{26}(\tau))$$
$$(\overline{\tau}_i = r) \Longrightarrow (\exists j \in \,]1, 1+|\tau|[\;.\; \exists w \in \mathfrak{Wi} \;.\; \overline{\tau}_j = \mathfrak{rf}[w, r]) \;.$$

communication (read-from) event

Axiomatic parameterized definition of the anarchic semantics

- Predictive evaluation of media variables:

$$\begin{array}{l} V^{p}_{(32)}[\![\mathtt{x}_\theta]\!](\tau, k) \ \triangleq\ v \ \ \textbf{where} \ \ \exists! i \in [1, 1 + |\tau|[\ .\ (\overline{\tau}_i = \mathfrak{r}(\langle p,\ \ell,\ \mathtt{r} := \mathtt{x},\ \theta\rangle, \mathtt{x}_\theta)) \wedge \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\ \exists! j \in [1, 1 + |\tau|[\ .\ (\overline{\tau}_j = \mathfrak{rf}[\mathfrak{w}(\langle p',\ \ell',\ \mathtt{x} := e',\ \theta'\rangle, v), \overline{\tau}_i]) \end{array}$$

- Local past-travel evaluation of an expression:

$$\begin{array}{lcll} E^{p}_{(30)}[\![\mathtt{r}]\!](\tau, k) & \triangleq & v & \text{if } k > 1 \wedge \big((\overline{\tau}_k = \mathfrak{a}(\langle p,\ \ell,\ \mathtt{r} := e,\ \theta\rangle, v)) \vee \\ & & & \qquad\qquad\quad (\overline{\tau}_k = \mathfrak{r}(\langle p,\ \ell,\ \mathtt{r} := \mathtt{x},\ \theta\rangle, \mathtt{x}_\theta) \wedge V^{p}[\![\mathtt{x}_\theta]\!](\tau, k) = v)\big) \\ E^{p}_{(30)}[\![\mathtt{r}]\!](\tau, 1) & \triangleq & I[\![0]\!] & \qquad\qquad\qquad\qquad i.e.\ \overline{\tau}_1 = \epsilon_{\mathsf{start}} \text{ by } \mathsf{Wf}_{15}(\tau) \\ E^{p}_{(30)}[\![\mathtt{r}]\!](\tau, k) & \triangleq & E^{p}_{(30)}[\![\mathtt{r}]\!](\tau, k - 1) & \qquad\qquad\qquad\qquad\qquad\qquad \text{otherwise.} \end{array}$$

Abstractions of the anarchic semantics

Abstractions

- Anarchic semantics:

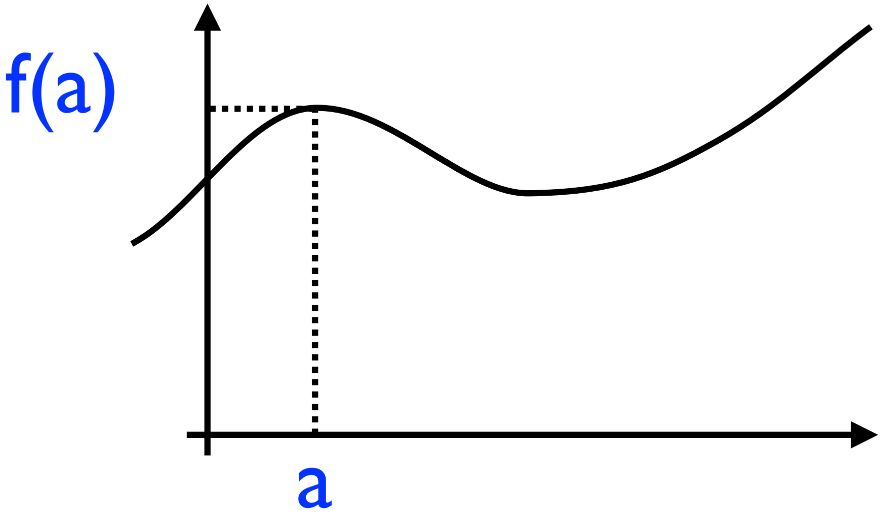
$$S^{\perp}[\![\mathrm{P}]\!] \triangleq \boldsymbol{\lambda}\,\underbrace{\langle \mathcal{B},\ \mathsf{sat},\ \mathcal{D},\ I,\ \mathfrak{S},\ V,\ E,\ N\rangle}_{\text{parameters of the semantics}} \bullet \{\tau \in \mathfrak{T}[\![\mathrm{P}]\!]|_{\cong} \mid \underbrace{\mathsf{Wf}_1\ (\tau) \wedge \ldots \wedge \mathsf{Wf}_{29}(\tau)}_{\text{trace well-formedness conditions}}\}$$

- Examples of abstractions:
  - Choose data (e.g. ground values, uninterpreted symbolic expressions, interpreted symbolic expressions i.e. “symbolic guess”)
  - Bind parameters (e.g. how expressions are evaluated)
  - …

Binding a parameter of the semantics

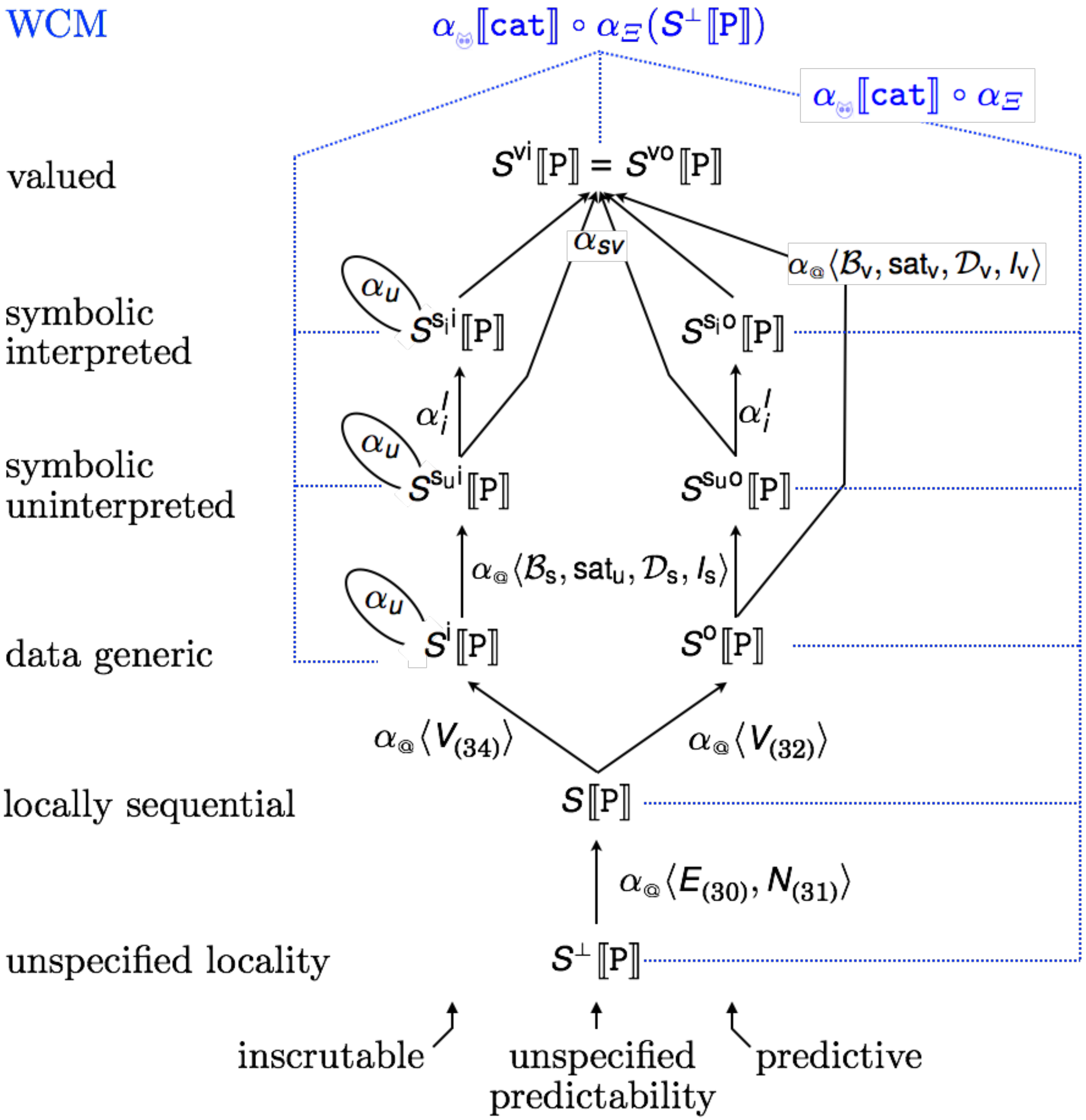
- The abstraction

$$\alpha_a(f) \overset{\text{def}}{=} f(a)$$



$$\begin{tikzcd}\langle \wp(A,B,\ldots)\longrightarrow\wp(R),\dot{\subseteq}\rangle \arrow[r, shift right, "\alpha_a"'] & \langle \wp(B,\ldots)\longrightarrow\wp(R),\dot{\subseteq}\rangle \arrow[l, shift right, "\gamma_a"']\end{tikzcd}$$

The hierarchy of interleaved semantics



True parallelism with local communications

- Extract from interleaved executions:
  - The subtrace of each process keeping communications in the process that read

⟹ no more global time between processes

⟹ local time between local actions and communications (a read can still tell when it is satisfied by which write)

True parallelism with local communications

- Interleaved execution:

global time →

t = $w(\text{start}, \mathrm{x}, 0)\ w(\text{start}, \mathrm{y}, 0)\ r(\mathtt{P0}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\mathtt{P0}, \mathrm{x}, 1)])\ w(\mathtt{P0}, \mathrm{y}, 1)\ r(\mathtt{P1}, \mathrm{y}, 1)$
$w(\mathtt{P1}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\mathtt{P1}, \mathrm{y}, 1)]\ r(\text{finish}, \mathrm{x})\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\text{finish}, \mathrm{x}, 1)]$
$r(\text{finish}, \mathrm{y}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\text{finish}, \mathrm{y}, 1)]$

- Parallel executions with interleaved communications:

t = Initialization: $w(\text{start}, \mathrm{x}, 0)\ w(\text{start}, \mathrm{y}, 0)$

local time →

P0: $r(\mathtt{P0}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\mathtt{P0}, \mathrm{x}, 1)])\ w(\mathtt{P0}, \mathrm{y}, 1)$

local time →

P1: $r(\mathtt{P1}, \mathrm{y}, 1)\ w(\mathtt{P1}, \mathrm{x}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\mathtt{P1}, \mathrm{y}, 1)]$

Finalization: $r(\text{finish}, \mathrm{x})\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\text{finish}, \mathrm{x}, 1)]$
$r(\text{finish}, \mathrm{y}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\text{finish}, \mathrm{y}, 1)]$

True parallelism of computations and communications

- Extract from interleaved executions:
  - The subtrace of each process (sequential execution of actions)
  - The rf communication relation (interactions between processes)

$\Longrightarrow$ no more global time between processes

$\Longrightarrow$ no more global/local time for communications

True parallelism with separate communications

- Parallel executions with interleaved communications:

Initialization: $w(\text{start}, \mathrm{x}, 0)\ w(\text{start}, \mathrm{y}, 0)$

P0: $r(\mathtt{P0}, \mathtt{x}, 1)\ w(\mathtt{P0}, \mathtt{y}, 1)$ *local time* →

P1: $r(\mathtt{P1}, \mathtt{y}, 1)\ w(\mathtt{P1}, \mathtt{x}, 1)$ *local time* →

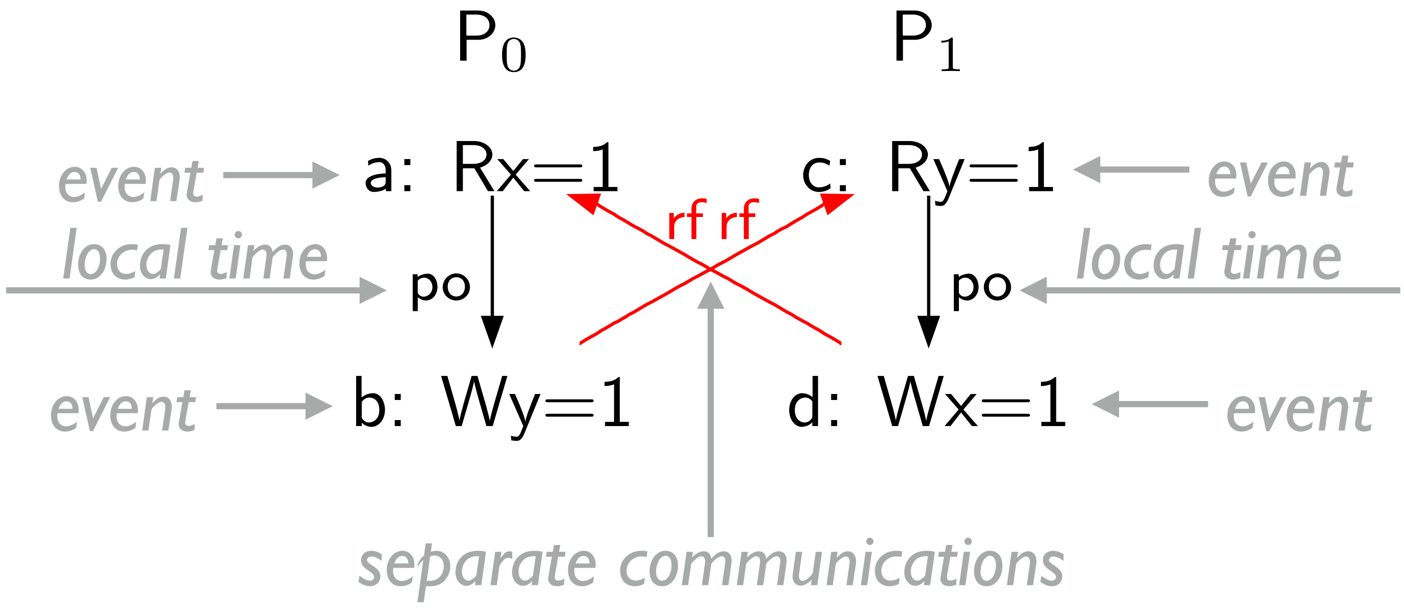
Finalization: $r(\text{finish}, \mathrm{x})\ \mathfrak{rf}[w(\mathtt{P1}, \mathrm{x}, 1), r(\text{finish}, \mathrm{x}, 1)]$
$r(\text{finish}, \mathrm{y}, 1)\ \mathfrak{rf}[w(\mathtt{P0}, \mathrm{y}, 1), r(\text{finish}, \mathrm{y}, 1)]$

Communications:

$\{\ \mathfrak{rf}[w(\mathtt{P1}, \mathtt{x}, 1), r(\mathtt{P0}, \mathtt{x}, 1)]),\ \mathfrak{rf}[w(\mathtt{P0}, \mathtt{y}, 1), r(\mathtt{P1}, \mathtt{y}, 1)]\ \}$

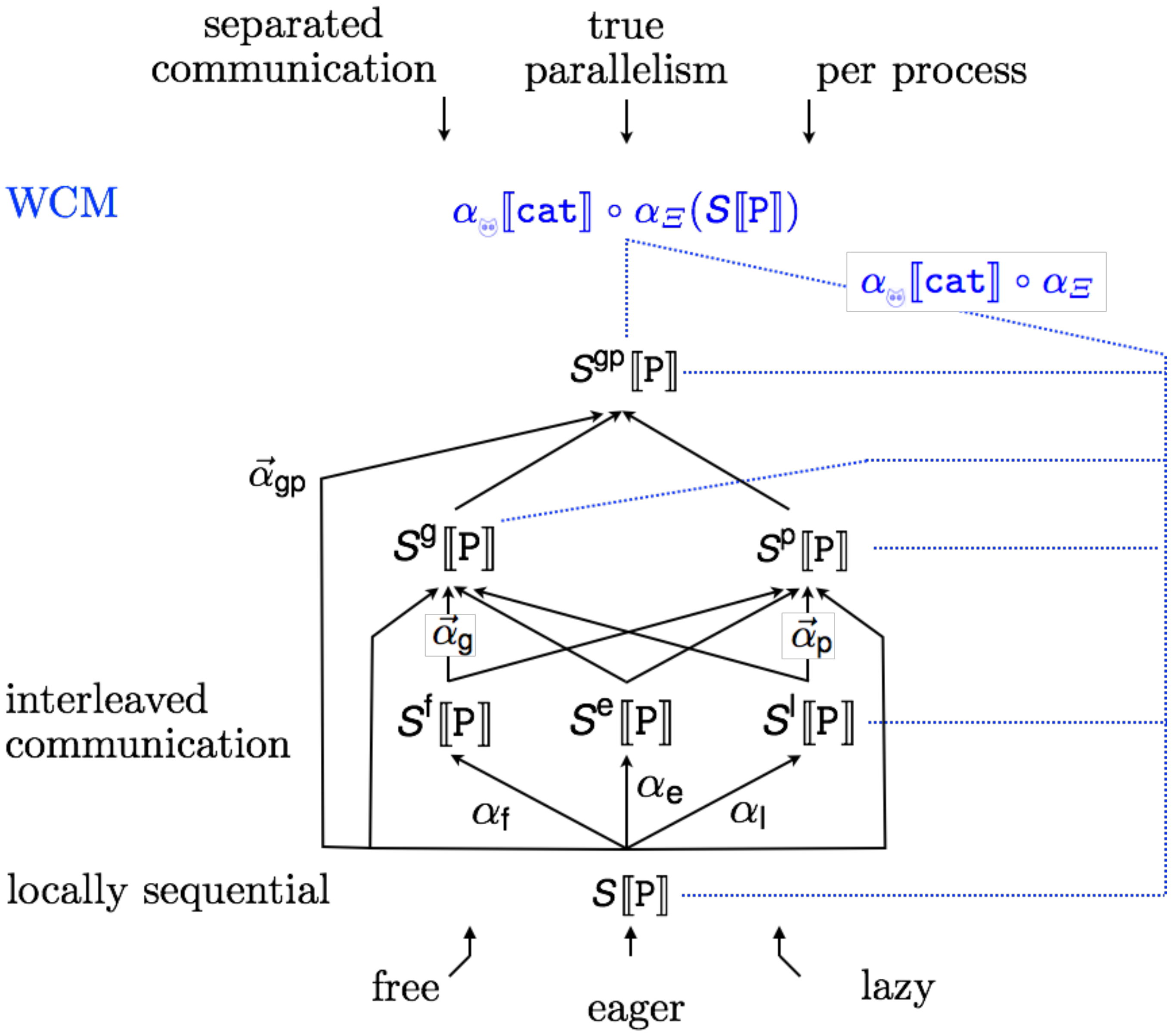
True parallelism with separate communications

- This is the semantics used by the herd7 tool:



+ interpreted symbolic expressions i.e. “symbolic guess”

The true parallelism hierarchy



States

- At each point in a trace, the state abstracts the past computation history up to that point
- Example: classical environment (assigning values to register at each point k of the trace):

$$\rho^p(\tau, k) \triangleq \boldsymbol{\lambda}\, \mathtt{r} \in \mathbb{R}(p) \bullet E^p[\![\mathtt{r}]\!](\tau, k)$$

$$\nu^p(\tau, k) \triangleq \boldsymbol{\lambda}\, \mathtt{x}_\theta \bullet V^p_{(32)}[\![\mathtt{x}_\theta]\!](\tau, k)$$

Prefixes, transitions, …

- Abstract traces by their prefixes:

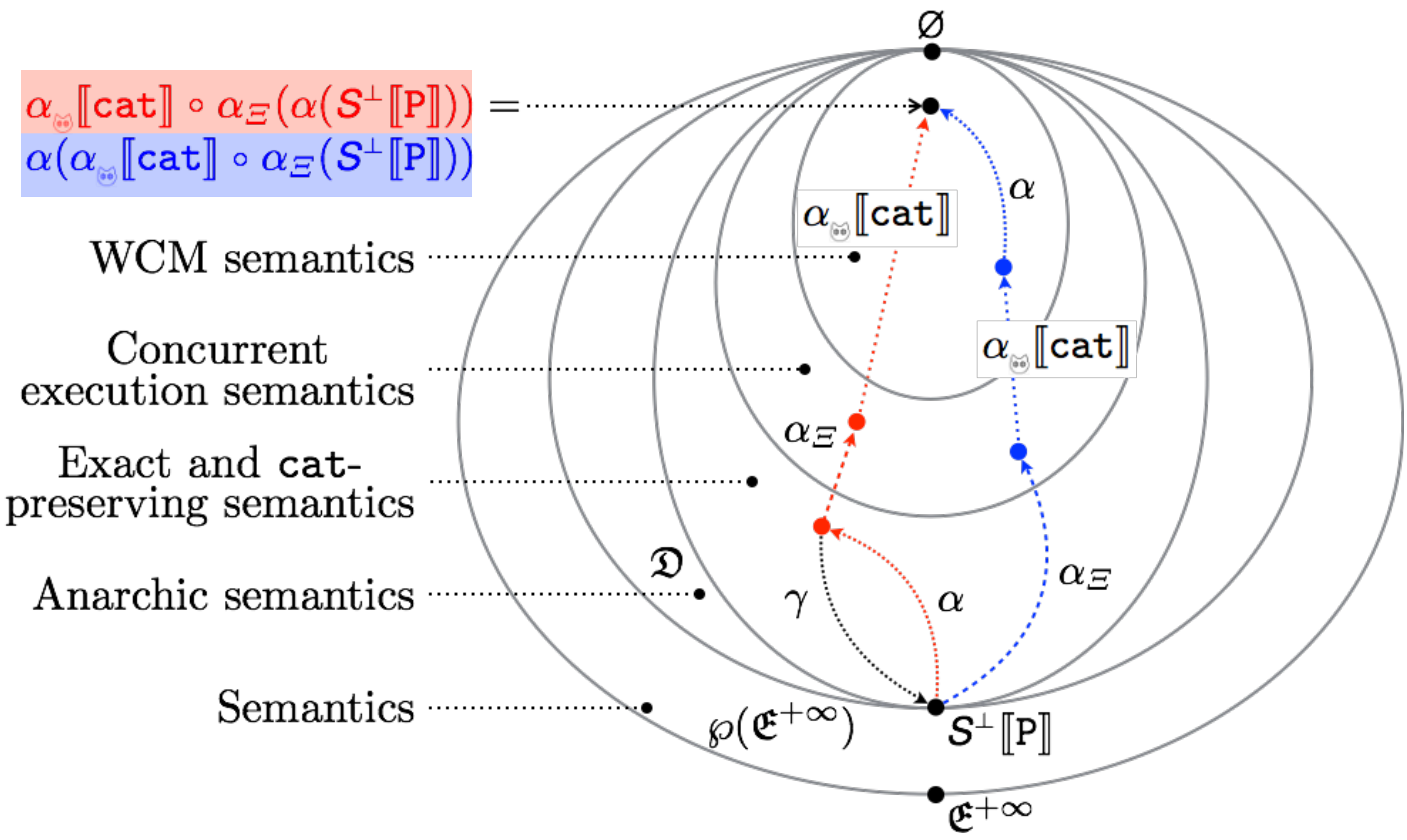
$$\begin{aligned}
\overleftarrow{\alpha}(\mathsf{S}) &\triangleq \bigcup\{\overleftarrow{\alpha}(\tau) \mid \tau \in \mathsf{S}\}\\
\overleftarrow{\alpha}(\tau) &\triangleq \{\tau\langle\!\langle j\langle\!\langle \mid j \in [1, 1+|\tau|[\}\\
\tau\langle\!\langle j\langle\!\langle &\triangleq \langle \xrightarrow{\overline{\tau}_i} \underline{\tau}_i \mid i \in [1, 1+j[\rangle
\end{aligned}$$

- and transitions: extract transitions from traces

$\Longrightarrow$ communication fairness is lost, inexact abstraction,
$\Longrightarrow$ add fairness condition
$\Longrightarrow$ impossible to implement with a scheduler ($\neq$ process fairness)

Effect of the cat specification on the hierarchy

Exactness and cat preservation



$$\alpha_{🐱}[\![\texttt{cat}]\!] \circ \alpha_{\Xi}(\alpha(S^{\perp}[\![\texttt{P}]\!])) = \alpha(\alpha_{🐱}[\![\texttt{cat}]\!] \circ \alpha_{\Xi}(S^{\perp}[\![\texttt{P}]\!]))$$

WCM semantics

Concurrent execution semantics

Exact and cat-preserving semantics

Anarchic semantics

Semantics

The cat abstraction

- The same cat specification $\alpha_{🐱}[\![\texttt{cat}]\!]$ applies equally to any concurrent execution abstraction α_{Ξ} of any interleaved/truly parallel semantics in the hierarchy
- The appropriate level of abstraction to specify WCM:
  - No states, only `marker` (`e.g. fence`), `r`, `w`, `rf(w,r)` events
  - No values in events
  - No global time (only `po` order of events per process)
  - Time of communications forgotten (only `rf` of who communicates with whom)

Conclusion

Conclusion

- Analytic semantics: a new style of semantics
- The hierarchy of anarchic semantics describes the same computations and potential communications in very different styles
- The cat semantics restricts communications to a machine/ network architecture in the same way for all semantics in the hierarchy
- This idea of parameterized semantics at various levels of abstraction is useful for
  - Verification
  - Static analysis

The End