Failure and Fault Tolerance in a distributed π-calculus

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Overview

- **Motivation:**
  - π-calculus overview
  - A distributed π-calculus
  - Failure in a distributed setting
- Behaviour and Partial Failure: DπF
- Dependability: Fault Tolerance

Starting Point: π-calculus Syntax

P, Q	::=	**stop**	(*inaction*)
	|	$a!\langle v\rangle.P$	(*output*)
	|	$a?(x).P$	(*input*)
	|	$*P$	(*replication*)
	|	if $v = u.P\lceil Q\rceil$	(*name matching*)
	|	$P\|Q$	(*parallel composition*)
	|	$(va)P$	(*hiding*)

π-calculus Reduction

(r-comm)

$$\frac{}{a!\langle b\rangle.P \mid a?(x).Q \longrightarrow P \mid Q\{^{b}/_{x}\}}$$

(r-par)

$$\frac{P \longrightarrow P'}{P \mid Q \longrightarrow P' \mid Q} \qquad \frac{P \longrightarrow P'}{Q \mid P \longrightarrow Q \mid P'}$$

(r-ncond)

$$\frac{}{\text{if } a=b.P\lceil Q\rceil \longrightarrow Q}\ a \neq b$$

(r-cond)

$$\frac{}{\text{if } a=a.P\lceil Q\rceil \longrightarrow P}$$

(r-rest)

$$\frac{P \longrightarrow P'}{(\nu a)P \longrightarrow (\nu a)P'}$$

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π-calculus Reduction(2)

(s-par)

$$P \mid Q \equiv Q \mid P$$

(s-inact)

$$P \mid \mathbf{stop} \equiv P$$

(s-repl)

$$*P \equiv *P \mid P$$

(s-rest)

$$P \mid (\nu a)Q \equiv (\nu a)(P \mid Q) \quad a \notin \mathbf{fn}(P)$$

(r-struct)

$$\frac{P \equiv P' \qquad P' \longrightarrow Q' \qquad Q' \equiv Q}{P \longrightarrow Q}$$

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π-calculus example: Client Server

$$\text{server} \Leftarrow (\nu\, data)\left(\begin{array}{l} req?(x_1, x_2).data!\langle x_1, x_2\rangle \\ \\ \mid data?(y_1, y_2).y_2!\langle\, \textbf{lookup}(y_1)\rangle \end{array}\right)$$

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$$\text{client} \Leftarrow req!\langle Adrian, ans\rangle \mid ans?(x)...$$

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$D\pi$ Sytnax

Processes

$$P, Q \quad ::= \quad \mathbf{stop} \quad a!\langle v\rangle.P \quad | \; a?(x).P \quad | \; *P$$
$$\quad | \quad \text{if } v = u.P\lceil Q\rceil \quad | \; P|Q \quad | \; (\nu a)P$$
$$\quad | \quad \text{go } l.P \quad (\textit{migration})$$

Systems

$$N, M \quad ::= \quad l[\![P]\!] \quad (\textit{located process})$$
$$\quad | \quad (\nu\, n)N \quad (\textit{network scoping})$$
$$\quad | \quad N|M \quad (\textit{parallel systems})$$

$D\pi$: Reduction Rules

(r-comm)

$$l[\![a!\langle n\rangle.P]\!] \mid l[\![a?(x).Q]\!] \longrightarrow l[\![P]\!] \mid l[\![Q\{^{n}/_{x}\}]\!]$$

(r-go)

$$l[\![\text{go } k.P]\!] \longrightarrow k[\![P]\!]$$

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$D\pi$ Example: Distributed Client Server

$$\text{server} \Leftarrow (\nu\, \mathit{data}) \left(\begin{array}{l} l[\![\mathit{req}?(x_1, x_2).\mathit{data}!\langle x_1, x_2\rangle]\!] \\ \\ \mid l[\![\mathit{data}?(y_1, y_2).y_2!\langle \mathbf{lookup}(y_1)\rangle]\!] \end{array} \right)$$

$$\text{serverLoc} \Leftarrow (\nu\, \mathit{data}) \left(\begin{array}{l} l[\![\mathit{req}?(x_1, x_2).\text{go}\, k_1.\mathit{data}!\langle x_1, x_2\rangle]\!] \\ \\ \mid k_1[\![\mathit{data}?(y_1, y_2).\text{go}\, l.y_2!\langle \mathbf{lookup}(y_1)\rangle]\!] \end{array} \right)$$

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$D\pi$ Example: Distributed Client Server

$$\text{serverLnk} \Leftarrow (\nu\, data)\left(\begin{array}{l} l\left[\!\left[req?(x_1, x_2).(\nu sync)\left(\begin{array}{l} \text{go } k_1.data!\langle x_1, sync\rangle \\ \mid \text{go } k_2, k_1.data!\langle x_1, sync\rangle \\ \mid sync?(z).x_2!\langle z\rangle \end{array}\right)\right]\!\right] \\ \mid k_1\left[\!\left[data?(y_1, y_2).\left(\begin{array}{l} \text{go } l.y_2!\langle \textbf{lookup}(y_1)\rangle \\ \mid \text{go } k_2, l.y_2!\langle \textbf{lookup}(y_1)\rangle \end{array}\right)\right]\!\right] \end{array}\right)$$

$D\pi$ Example: Distributed Client Server

$$\text{serverLnk} \Leftarrow (\nu\, data)\left(\begin{array}{l} l[\![\, req?(x_1, x_2).(\nu sync)\left(\begin{array}{l} \text{go}\, k_1.data!\langle x_1, sync\rangle \\ \mid \text{go}\, k_2,\ k_1.data!\langle x_1, sync\rangle \\ \mid sync?(z).x_2!\langle z\rangle \end{array}\right)\,]\!] \\ \\ \mid k_1[\![\, data?(y_1, y_2).\left(\begin{array}{l} \text{go}\, l.y_2!\langle \textbf{lookup}(y_1)\rangle \\ \mid \text{go}\, k_2,\ l.y_2!\langle \textbf{lookup}(y_1)\rangle \end{array}\right)\,]\!] \end{array}\right)$$

Reduction Closed Relations

$$M \quad \mathcal{R} \quad N$$

Reduction Closed Relations

$$M \quad \mathcal{R} \quad N$$
$$\downarrow$$
$$M'$$

Reduction Closed Relations

$$\begin{array}{ccc} M & \mathcal{R} & N \\ \downarrow & & \Downarrow \\ M' & \mathcal{R} & N' \end{array}$$

$D\pi$ Equivalence

Barbs

$M \Downarrow_{a@l}$ iff $M \Longrightarrow \equiv (\nu \tilde{n}) M' \mid l[\![a!\langle n \rangle.Q]\!]$ where $l, a \notin \tilde{n}$

$D\pi$ Equivalence

Barbs

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Barb Preserving Relation

$M \mathcal{R} N$ and $M \Downarrow_{a@l}$ implies $N \Downarrow_{a@l}$

Contextual Relation

$M \mathcal{R} N$ implies $\forall O$ we infer $M \mid O \ \mathcal{R} \ N \mid O$

and $O \mid M \ \mathcal{R} \ O \mid N$

$D\pi$ Equivalence

Reduction Barbed Congruence

The *largest* relation over *systems*, denoted by $\cong$, that is:

- reduction closed
- barb preserving
- contextual

$D\pi$ Equivalence: Application

According to this equivalence

$$\text{server} \cong \text{serverLoc} \cong \text{serverLnk}$$

$D\pi$ Equivalence: Application

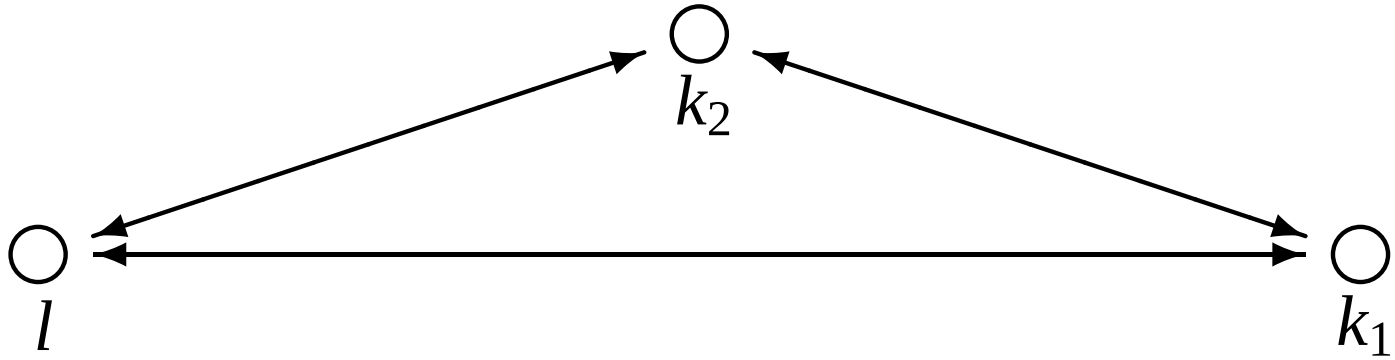
According to this equivalence

$$\text{server} \cong \text{serverLoc} \cong \text{serverLnk}$$

This only holds if :

- no node fails
- every node is interconnected (clique)

The Underlying Network



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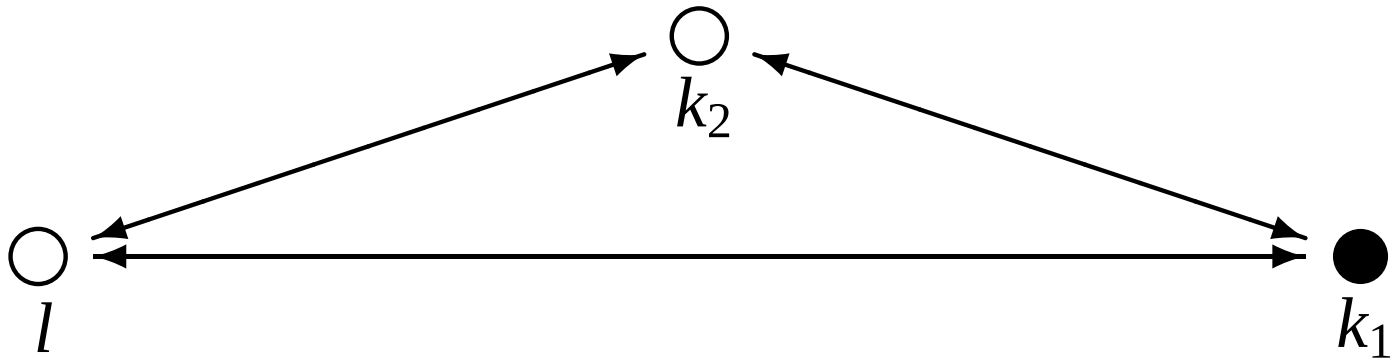

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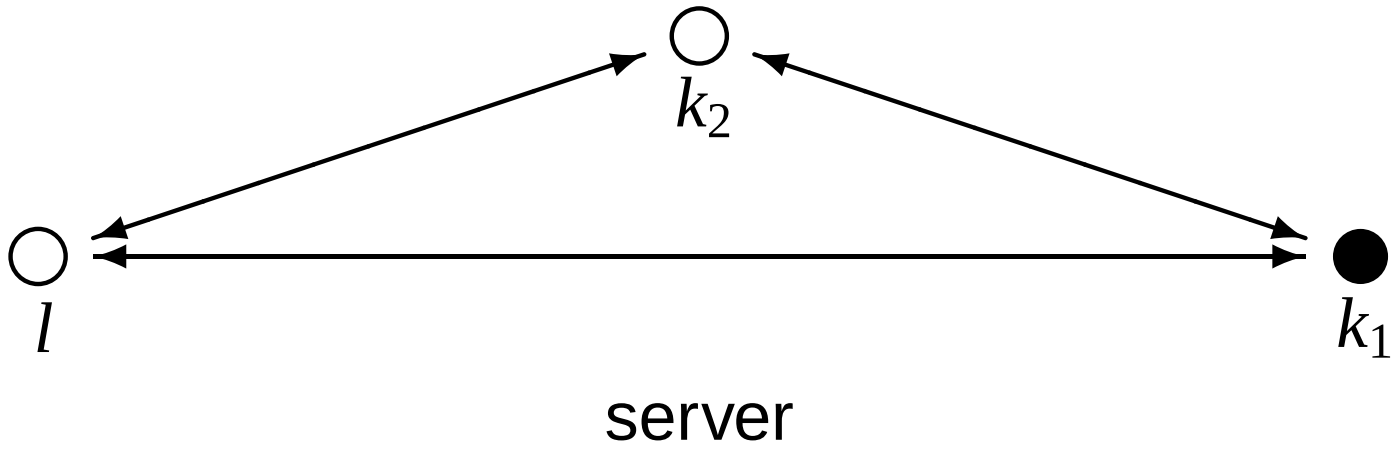

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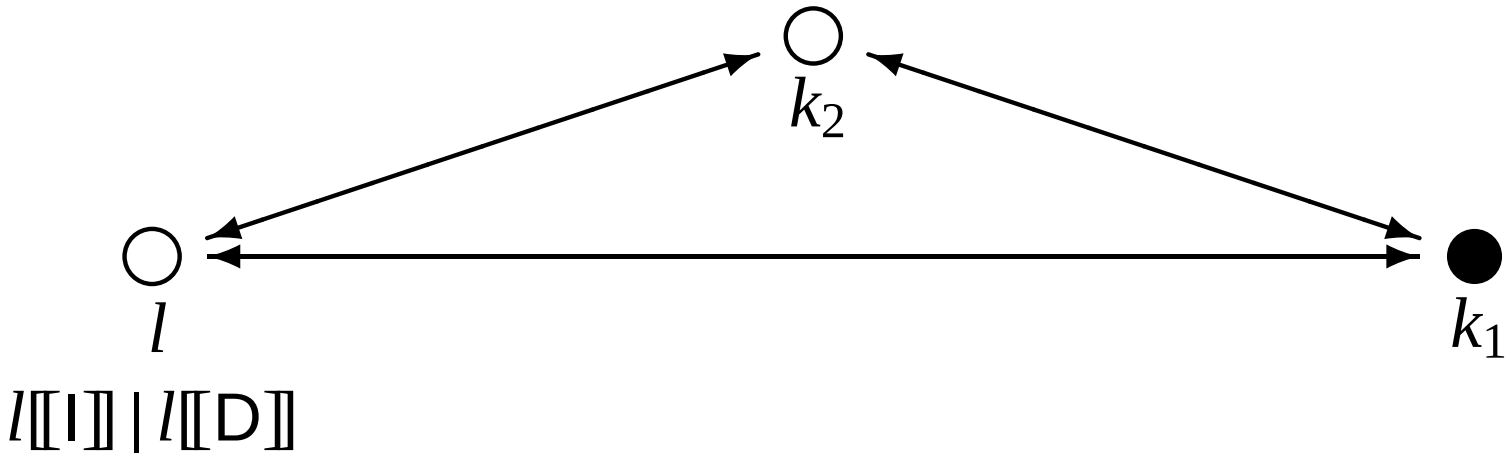

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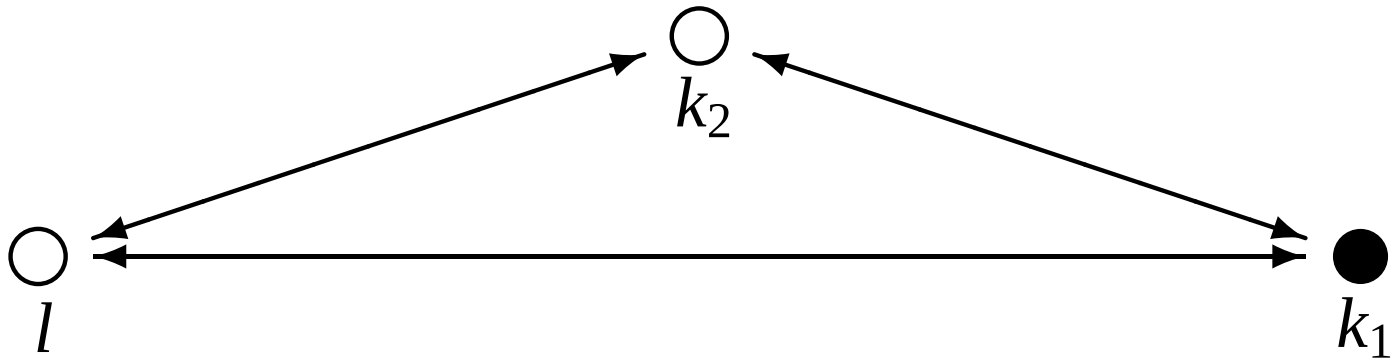
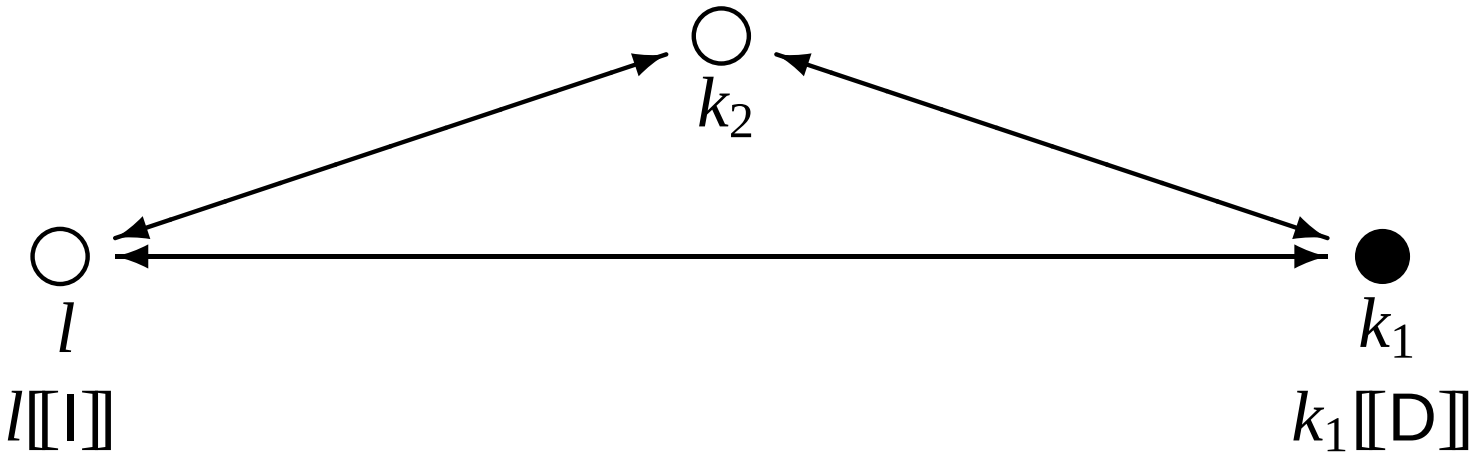


serverLoc

The Underlying Network



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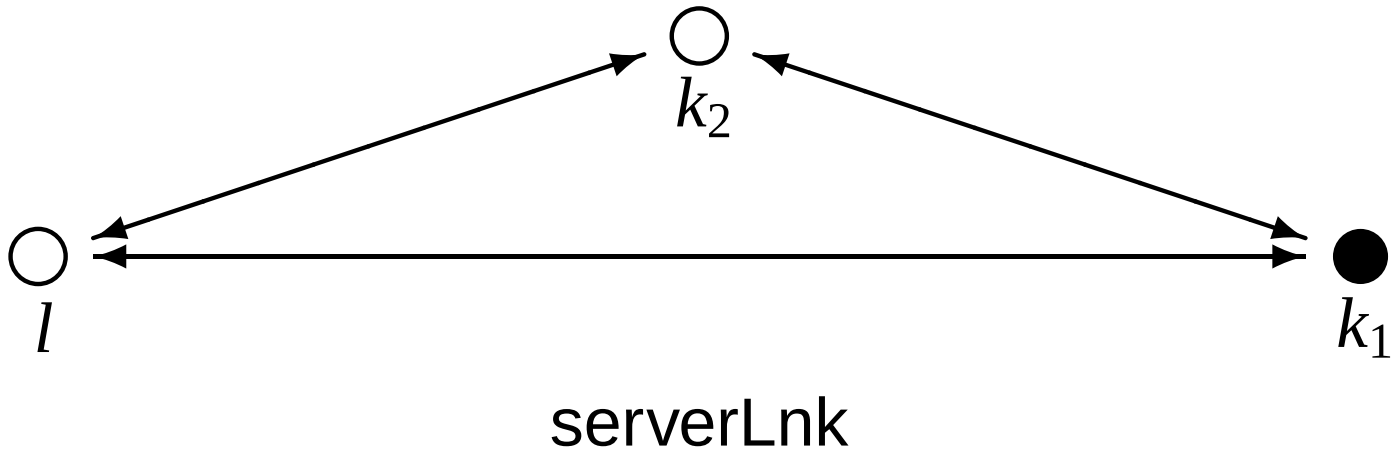

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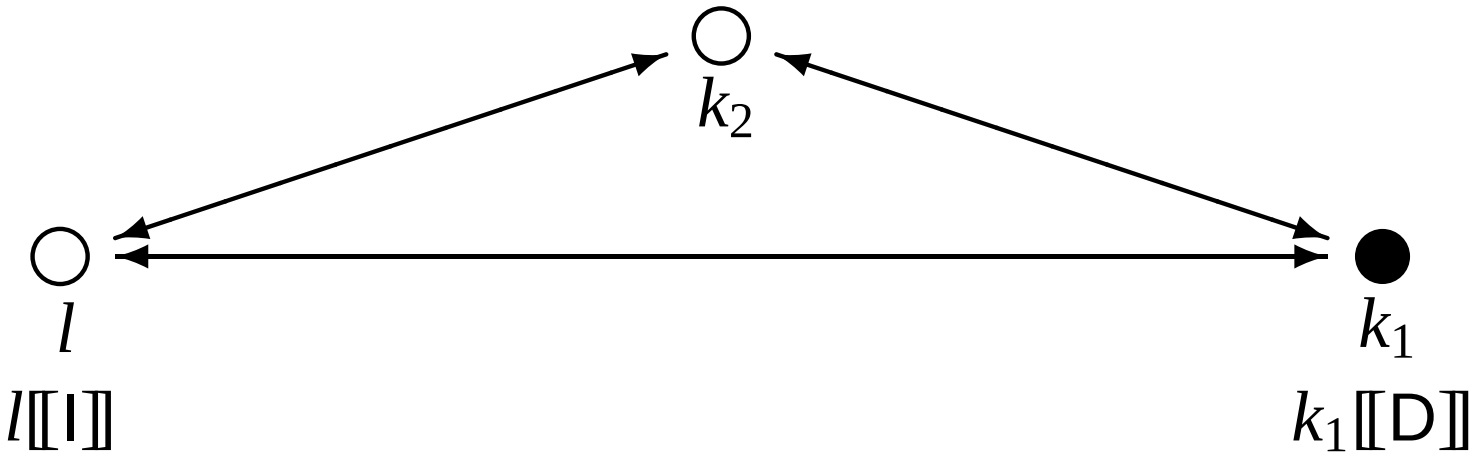

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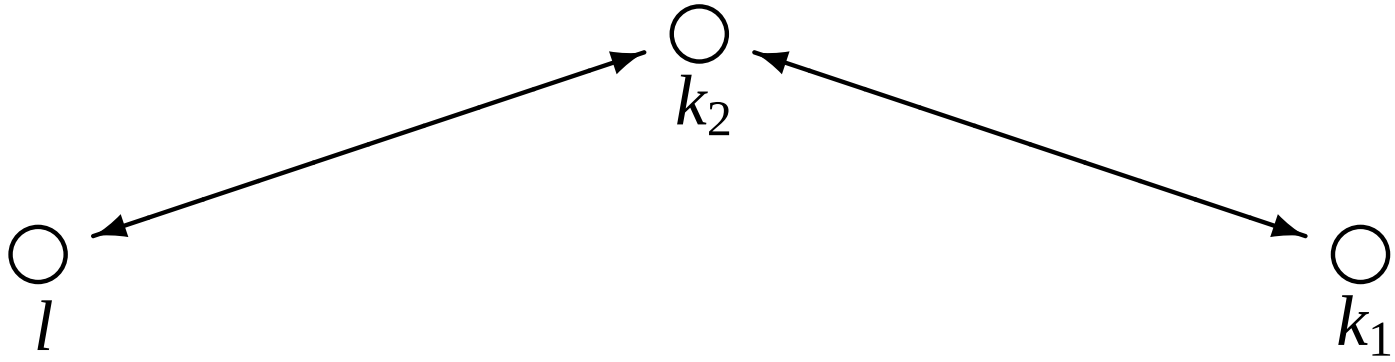

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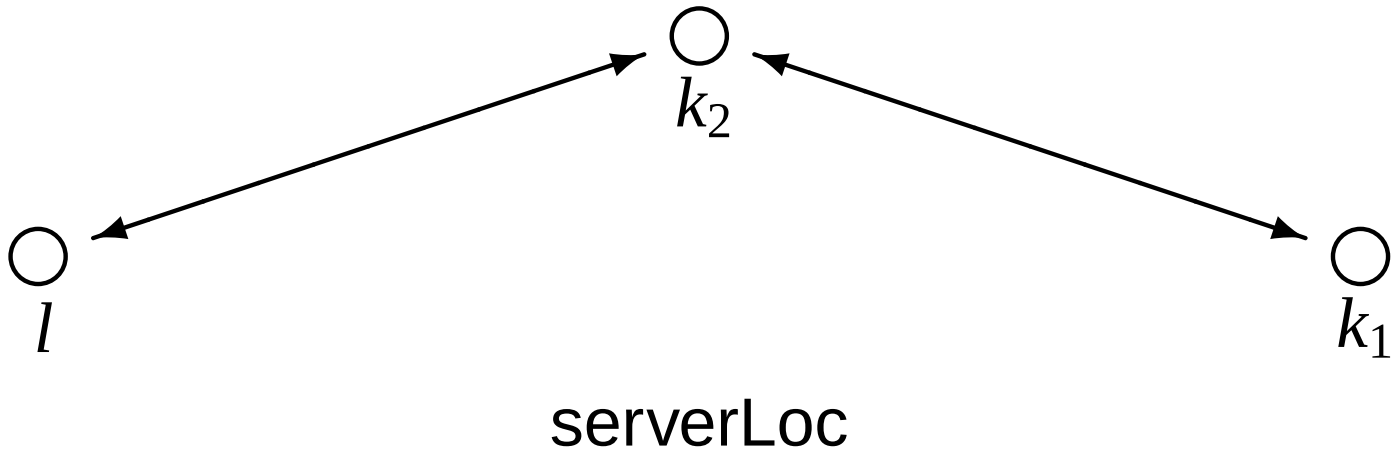

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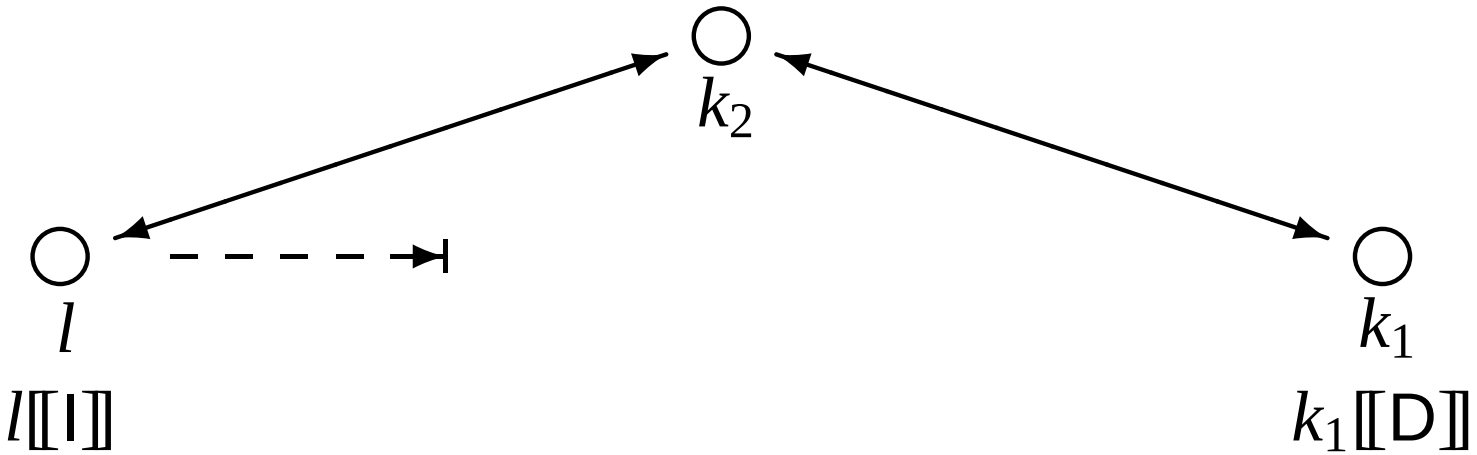

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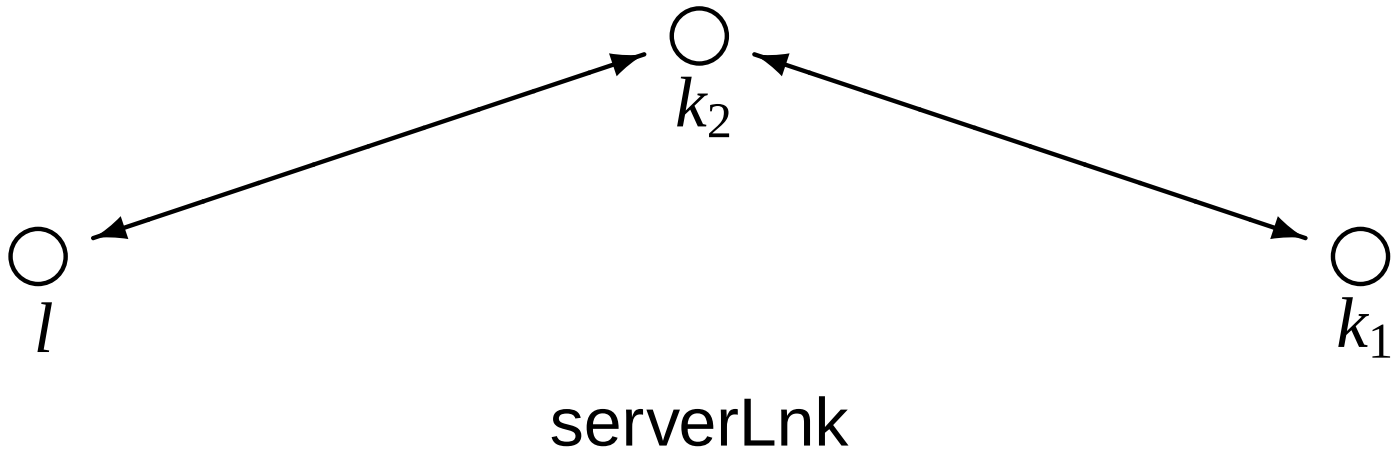

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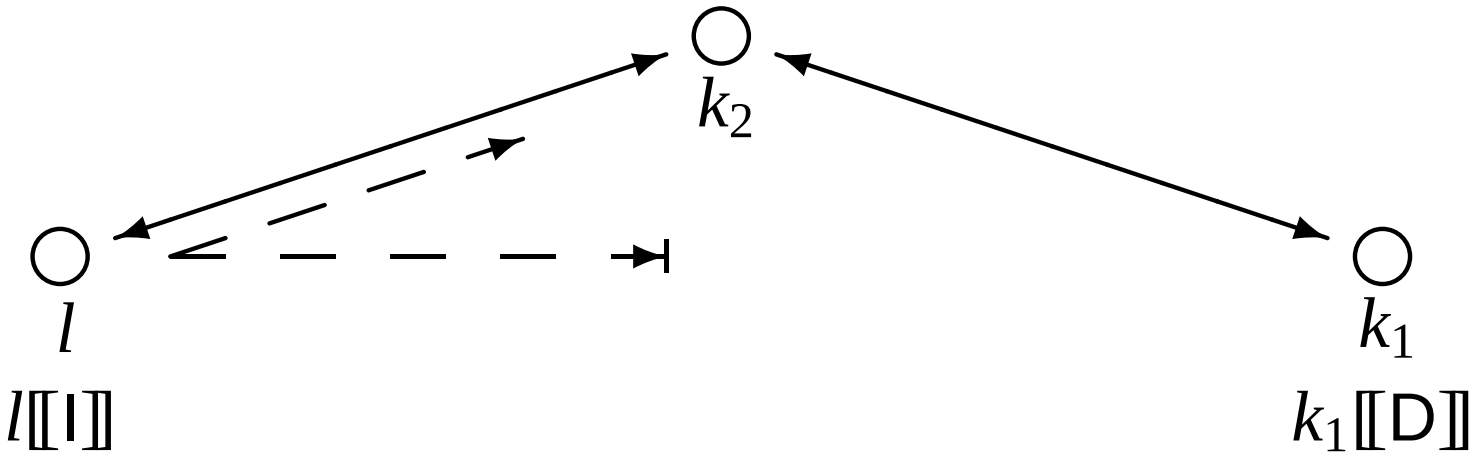

$D\pi$ Scope Extrusion Example

$$\mathsf{M} \Leftarrow (\nu\, k)(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

$$\mathsf{N} \Leftarrow (\nu\, k)(l[\![a!\langle k\rangle]\!] \mid k[\![c!\langle\rangle]\!])$$

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$$\mathsf{O} \Leftarrow l[\![a?(x).\mathsf{go}\ x.b?().\mathsf{go}\ l.\mathsf{ok}!\langle\rangle]\!]$$

$$\mathsf{M}|\mathsf{O} \Downarrow_{\mathsf{ok}@l}$$

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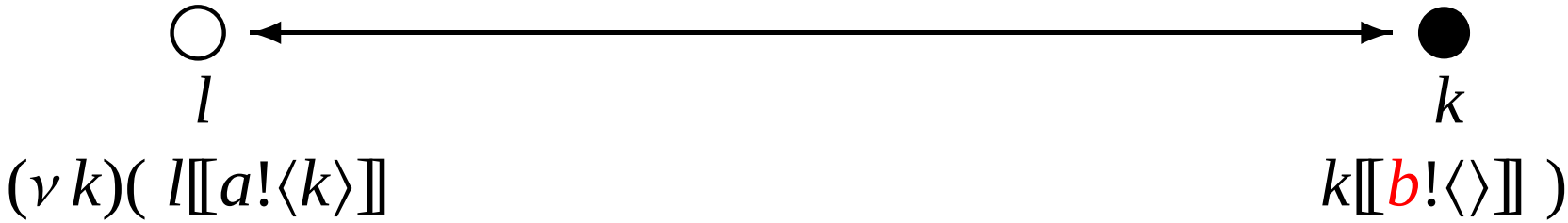

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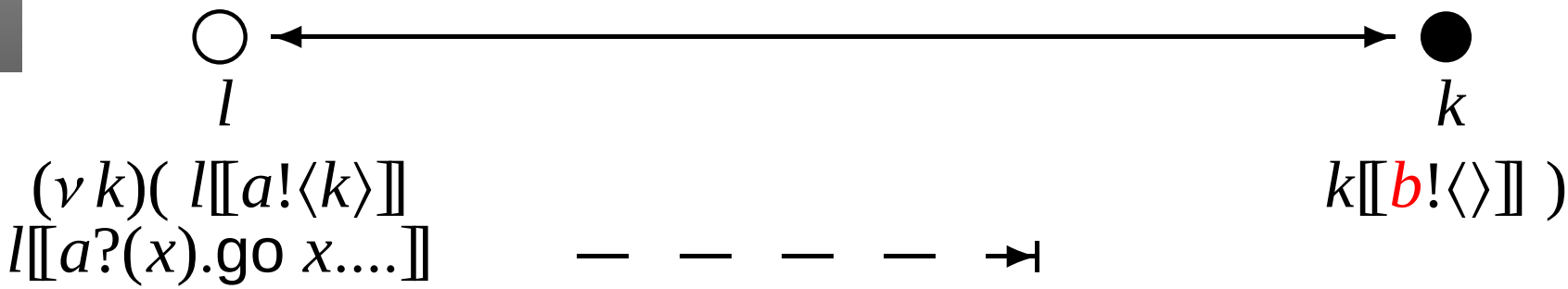

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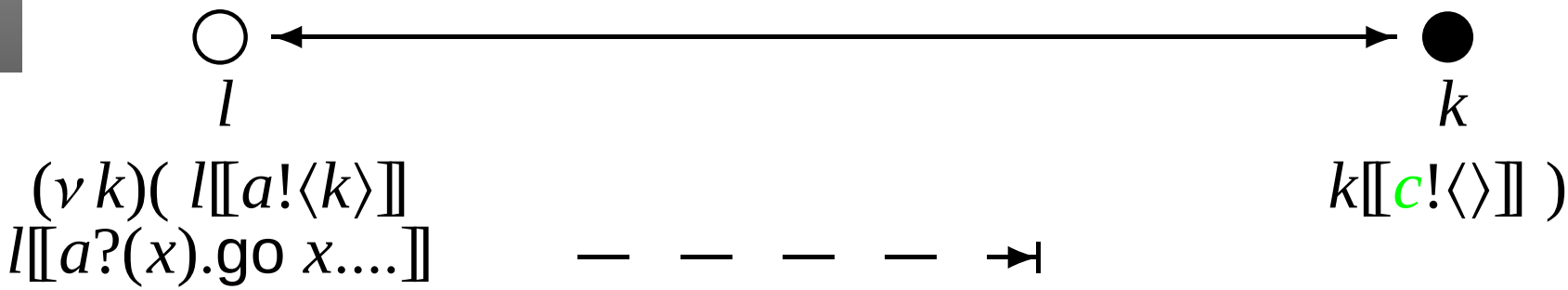

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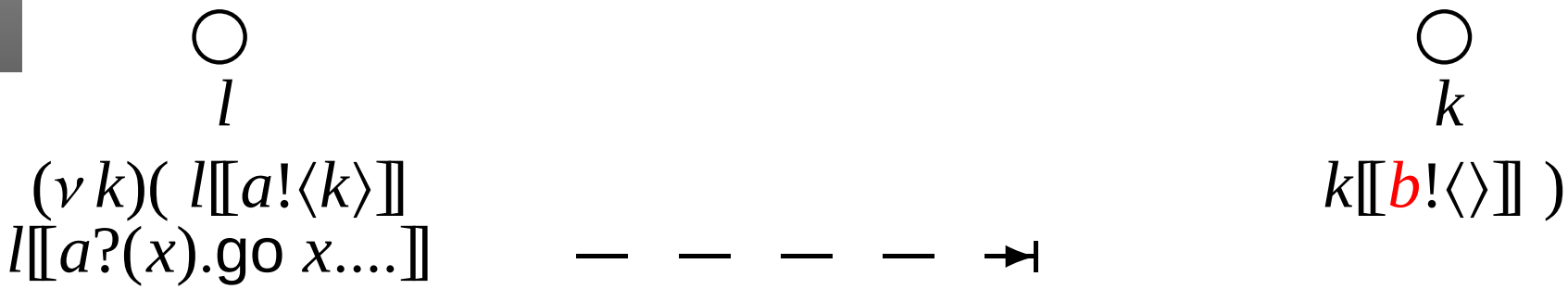

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$$\mathsf{M}|\mathsf{O}\Downarrow\!\!\!\!\!\!\not\quad_{\mathsf{ok}@l}$$
$$\mathsf{N}|\mathsf{O}\Downarrow\!\!\!\!\!\!\not\quad_{\mathsf{ok}@l}$$

$\mathsf{M} \cong \mathsf{N}$ for certain networks

Overview

- Motivation:
  - π-calculus overview
  - A distributed π-calculus
  - Failure in a distributed setting
- **Behaviour and Partial Failure: DπF**
- Dependability: Fault Tolerance

$D\pi F$: $D\pi$ with failure

Types

$$\begin{array}{rcll} \mathtt{T}, \mathtt{U} & ::= & \mathtt{loc}[\mathtt{A}, \{l_1, .., l_n\}] & |\,\mathtt{ch} \\ \mathtt{A} & ::= & \mathtt{a} \,|\, \mathtt{d} & \end{array}$$

Processes

$$\begin{array}{rcll} P, Q & ::= & \ldots & \\ & | & (\nu\, n : \mathtt{T})P & (\textit{typed scoping}) \\ & | & \mathsf{kill} & (\textit{kill location}) \\ & | & \mathsf{break}\ l & (\textit{break link}) \\ & | & \mathsf{ping}\ l.P\lceil Q \rceil & (\textit{ping}) \end{array}$$

$D\pi F$: $D\pi$ with failure

Systems

$$N, M \quad ::= \quad \ldots \quad | (\nu\, n : \mathtt{T}) N$$

We work at the level of **Configurations**

$$\Gamma \triangleright M$$

where Γ is a network representation

$D\pi F$: $D\pi$ with failure

(r-comm)

$$\frac{\Gamma \vdash l : \textbf{alive}}{\Gamma \triangleright l[\![a!\langle n\rangle.P]\!] \mid l[\![a?(x).Q]\!] \longrightarrow \Gamma \triangleright l[\![P]\!] \mid l[\![Q\{^{n}/_{x}\}]\!]}$$

(r-go)

$$\frac{\Gamma \vdash l : \textbf{alive} \qquad \Gamma \vdash k : \textbf{alive} \qquad \Gamma \vdash l \leftrightarrow k}{\Gamma \triangleright l[\![\text{go } k.P]\!] \longrightarrow \Gamma \triangleright k[\![P]\!]}$$

$D\pi F$: $D\pi$ with failure

(r-kill)

$$\frac{\Gamma \vdash l : \mathbf{alive}}{\Gamma \triangleright l[\![\mathsf{kill}]\!] \longrightarrow \Gamma - l \triangleright l[\![\mathbf{stop}]\!]}$$

(r-brk)

$$\frac{\Gamma \vdash l : \mathbf{alive} \qquad \Gamma \vdash l \leftrightarrow k}{\Gamma \triangleright l[\![\mathsf{break}\ k]\!] \longrightarrow \Gamma - l \leftrightarrow k \triangleright l[\![\mathbf{stop}]\!]}$$

$D\pi F$: $D\pi$ with failure

(r-ping)

$$\frac{\Gamma \vdash l : \mathbf{alive} \qquad \Gamma \vdash k : \mathbf{alive} \qquad \Gamma \vdash l \leftrightarrow k}{\Gamma \triangleright l[\![\text{ping } k.P\lceil Q\rceil]\!] \longrightarrow \Gamma \triangleright l[\![P]\!]}$$

(r-nping1)

$$\frac{\Gamma \vdash l : \mathbf{alive} \qquad \Gamma \vdash k : \mathbf{dead}}{\Gamma \triangleright l[\![\text{ping } k.P\lceil Q\rceil]\!] \longrightarrow \Gamma \triangleright l[\![Q]\!]}$$

(r-nping2)

$$\frac{\Gamma \vdash l : \mathbf{alive} \qquad \Gamma \vdash l \nleftrightarrow k}{\Gamma \triangleright l[\![\text{ping } k.P\lceil Q\rceil]\!] \longrightarrow \Gamma \triangleright l[\![Q]\!]}$$

DπF Example

$$\mathsf{M} \quad \Leftarrow \quad (\nu\, k : \mathtt{loc[a, \{}l\mathtt{\}]})(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

If $\Gamma \vdash l$: **alive**

DπF Example

$$\mathsf{M} \quad \Leftarrow \quad (\nu\, k : \mathtt{loc[d, \{}l\mathtt{\}]})(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

If $\Gamma \vdash l$: **alive**

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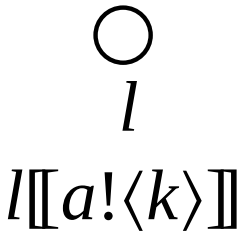

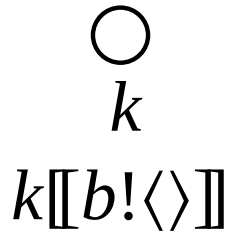

Barbs

$\Gamma \triangleright M{\Downarrow_{a@l}}$ iff $M \Longrightarrow \equiv (\nu \tilde{n})M' \mid l[\![a!\langle n \rangle.Q]\!]$
where $l, a \notin \tilde{n}$ and $\Gamma \vdash l$: **alive**

Contextual Relation

$\Gamma \models M \ \mathcal{R} \ N$ implies $\forall O$ we infer $\Gamma \models M \mid O \ \mathcal{R} \ N \mid O$

and $\Gamma \models O \mid M \ \mathcal{R} \ O \mid N$

and $\Gamma + n : \mathtt{T} \models M \ \mathcal{R} \ N$

Reduction Barbed Congruence

The *largest* relation over *systems*, running over the *same network* denoted by $\Gamma \models M \cong N$, that is:

- reduction closed
- barb preserving
- contextual

DπF bisimulation

DπF lts over configurations

$$\Gamma \triangleright M \xrightarrow{\mu} \Gamma' \triangleright M'$$

where μ is either:

- τ (internal action)
- $(\tilde{n} : \tilde{\mathrm{T}})l : a!\langle V \rangle$ (bound output)
- $(\tilde{n} : \tilde{\mathrm{T}})l : a?(V)$ (bound input)
- kill : k (external kill)
- $l \leftrightarrow k$ (external break)

DπF bisimulation

(l-out)

$$\frac{\Gamma \vdash l : \mathbf{alive}}{\Gamma \triangleright l[\![a!\langle V\rangle.P]\!] \xrightarrow{l:a!\langle V\rangle} \Gamma \triangleright l[\![P]\!]}$$

(l-open)

$$\frac{\Gamma + n:\mathtt{T} \triangleright M \xrightarrow{(\tilde{}n\,\tilde{\mathtt{T}})l:a!\langle V\rangle} \Gamma' \triangleright M'}{\Gamma \triangleright (\nu\, n:\mathtt{T})M \xrightarrow{(n:\mathtt{T},\tilde{}n\,\tilde{\mathtt{T}})l:a!\langle V\rangle} \Gamma' \triangleright M'}\; l, a \neq n$$

$D\pi F$ bisimulation

(r-go)

$$\frac{\Gamma \vdash l : \textbf{alive} \qquad \Gamma \vdash k : \textbf{alive} \qquad \Gamma \vdash l \leftrightarrow k}{\Gamma \triangleright l[\![\text{go } k.P]\!] \xrightarrow{\tau} \Gamma \triangleright k[\![P]\!]}$$

(r-kill)

$$\frac{\Gamma \vdash l : \textbf{alive}}{\Gamma \triangleright M \xrightarrow{\text{kill}:l} \Gamma - l \triangleright M}$$

$D\pi F$ bisimulation

Weak bisimulation equivalence, denoted as $\approx_{bad}$, is the *largest symmetric* relation over *configurations* such that whenever $\Gamma_1 \triangleright M_1 \approx \Gamma_2 \triangleright M_2$ then:

- $\Gamma_1 \triangleright M_1 \xrightarrow{\mu} \Gamma_1' \triangleright M_1'$ implies $\Gamma_2 \triangleright M_2 \stackrel{\hat{\mu}}{\Longrightarrow} \Gamma_2' \triangleright M_2'$ such that $\Gamma_1' \triangleright M_1' \approx \Gamma_2' \triangleright M_2'$
- $\Gamma_2 \triangleright M_2 \xrightarrow{\mu} \Gamma_2' \triangleright M_2'$ implies $\Gamma_1 \triangleright M_1 \stackrel{\hat{\mu}}{\Longrightarrow} \Gamma_1' \triangleright M_1'$ such that $\Gamma_1' \triangleright M_1' \approx \Gamma_2' \triangleright M_2'$

$D\pi F$ bisimulation

But $\approx_{\text{bad}}$ is **too intensional!**

$$\mathsf{M} \Leftarrow (\nu\, k : \mathtt{loc}[\mathtt{d}, \{l\}])(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

$$\mathsf{N} \Leftarrow (\nu\, k : \mathtt{loc}[\mathtt{a}, \emptyset])(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

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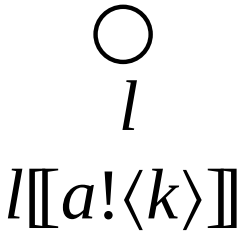

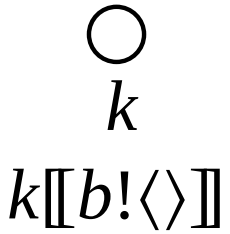

$D\pi F$ bisimulation

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For $\Gamma \vdash l$: **alive**

$$\Gamma \models \mathsf{M} \;\cong\; \mathsf{N}$$

$D\pi F$ bisimulation

But $\approx_{\mathsf{bad}}$ is **too intensional!**

$$\mathsf{M} \Leftarrow (\nu\, k : \mathtt{loc}[\mathtt{d}, \{l\}])(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

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However

$$\Gamma \models \mathsf{M} \not\approx_{\mathsf{bad}} \mathsf{N}$$

$D\pi F$ bisimulation

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However

$$\Gamma \models \mathsf{M} \not\approx_{\mathsf{bad}} \mathsf{N}$$

$$\Gamma \triangleright \mathsf{M} \xrightarrow{(k:\mathtt{loc[d,\{}l\mathtt{\}]})l:a!\langle k\rangle} \ldots$$

$D\pi F$ bisimulation

But $\approx_{\mathsf{bad}}$ is **too intensional!**

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$$\Gamma \triangleright \mathsf{M} \xrightarrow{(k:\mathtt{loc[d,\{}l\mathtt{\}]})l:a!\langle k\rangle} \ldots$$

$$\Gamma \triangleright \mathsf{N} \xrightarrow{(k:\mathtt{loc[a,}\emptyset\mathtt{]})l:a!\langle k\rangle} \ldots$$

$D\pi F$ bisimulation

Solution:

1. New network representation Σ showing *observer's view of the network*
2. Derived actions: $\Sigma \triangleright M \overset{\alpha}{\longmapsto} \Sigma' \triangleright M'$
3. Filter label: $(\tilde{n} : \tilde{\mathrm{T}})l : a!\langle V \rangle$ to $(\tilde{n} : \tilde{\mathrm{S}})l : a!\langle V \rangle$
4. New bisimulation, $\approx$, defined over new *derived* actions α.

$D\pi F$ bisimulation

$$\mathsf{M} \Leftarrow (\nu\, k : \mathtt{loc[d, \{}l\mathtt{\}]})(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

$$\mathsf{N} \Leftarrow (\nu\, k : \mathtt{loc[a, \emptyset]})(l[\![a!\langle k\rangle]\!] \mid k[\![b!\langle\rangle]\!])$$

We now have

$$\Gamma \models \mathsf{M} \approx \mathsf{N}$$

$$\Sigma(\Gamma) \triangleright \mathsf{M} \xrightarrow{(k:\mathtt{loc[\emptyset]})l:a!\langle k\rangle} \ldots$$

$$\Sigma(\Gamma) \triangleright \mathsf{N} \xrightarrow{(k:\mathtt{loc[\emptyset]})l:a!\langle k\rangle} \ldots$$

Results

Soundness

$\Sigma(\Gamma) \models M \approx N$ implies $\Gamma \models M \cong N$

Completness

$\Gamma \models M \cong N$ implies $\Sigma(\Gamma) \models M \approx N$

Overview

- Motivation:
  - π-calculus overview
  - A distributed π-calculus
  - Failure in a distributed setting
- Behaviour and Partial Failure: DπF
- **Dependability: Fault Tolerance**

Fault Tolerance Example

$$\text{serverLoc} \Leftarrow (\nu\, data)\left(\begin{array}{l} l[\![req?(x_1, x_2).\text{go}\, k_1.data!\langle x_1, x_2\rangle]\!] \\ \\ \mid k_1[\![data?(y_1, y_2).\text{go}\, l.y_2!\langle \textbf{lookup}(y_1)\rangle]\!] \end{array}\right)$$

Fault Tolerance Example

$$\text{server2} \quad \Leftarrow \quad (\nu\, data)\left(\begin{array}{l} l\left[\!\left[req?(x_1, x_2).(\nu sync)\left(\begin{array}{l} \text{go } k_1.data!\langle x_1, sync\rangle \\ \mid \text{go } k_2.data!\langle x_1, sync\rangle \\ \mid sync?(z).x_2!\langle z\rangle \end{array}\right)\right]\!\right] \\ \\ \mid k_1[\![data?(y_1, y_2).\text{go } l.y_2!\langle \textbf{lookup}(y_1)\rangle]\!] \\ \mid k_2[\![data?(y_1, y_2).\text{go } l.y_2!\langle \textbf{lookup}(y_1)\rangle]\!] \end{array}\right)$$

Fault Tolerance Example

$$\text{srvPng} \Leftarrow (\nu\, data)\left(\begin{array}{l} l[\![\; serv?(x,y).\text{ping}\, k_1.\text{go}\, k_1.data!\langle x,y\rangle \\ \qquad\qquad \lceil \text{go}\, k_2.data!\langle x,y\rangle \rceil \;]\!] \\ \mid k_1[\![data?(x,y).\text{go}\, l\, .y!\langle \textbf{lookup}(x)\rangle]\!] \\ \mid k_2[\![data?(x,y).\text{go}\, l\, .y!\langle \textbf{lookup}(x)\rangle]\!] \end{array}\right)$$

Fault Tolerance Intuition

$server_2$ is *more fault tolerant than* serverLoc because

"it preserves its (entire) observable behaviour up to a limit n of faults injected"

Fault Tolerance Intuition

$server_2$ is *more fault tolerant than* serverLoc because

"it preserves its (entire) observable behaviour up to a limit n of faults injected"

- How and where to inject faults?
- What is observable behaviour?
- How to limit observation?

Internal and External View

Partition locations in Γ into two:

- Public: $\Gamma \vdash l : \mathtt{p}$
- Confined: $\Gamma \vdash l : \mathtt{c}$

Internal and External View

Partial View

- limit observer to *public* locations

$$\Gamma \vdash_{\text{obs}} O \quad \text{if } \mathbf{fn}(O) \in \text{Pub}(\Gamma)$$

- *never communicate confined* locations to the observer: guaranteed through a type system

Internal and External View

Partial View

- limit observer to *public* locations

$$\Gamma \vdash_{\mathsf{obs}} O \quad \text{if } \mathbf{fn}(O) \in \mathrm{Pub}(\Gamma)$$

- never communicate confined locations to the observer: guaranteed through aType System

Example

$$\text{If } \Gamma \vdash l : \mathrm{p},\ k : \mathrm{c}$$

$$\Gamma \vdash_{\mathsf{obs}} l[\![a!\langle b\rangle]\!]$$
$$\Gamma \not\vdash l[\![a!\langle k\rangle]\!]$$

Internal and External View

Partial View Barbs

$$\Gamma \triangleright M{\Downarrow_{a@l}} \text{ iff } M \Longrightarrow \equiv (\nu \tilde{n})M' \mid l[\![a!\langle n\rangle.Q]\!]$$
where $l, a \notin \tilde{n}$ and $\Gamma \vdash l$: **alive**, p

Partial View Contextual Relation

$$\Gamma \models M \ \mathcal{R} \ N \quad \text{if} \quad \forall O.\, \Gamma \vdash_{\text{obs}} O \text{ then } \Gamma \models M \mid O \ \mathcal{R} \ N \mid O \text{ and } \Gamma \models O \mid M \ \mathcal{R} \ O \mid N \ \ldots$$

Internal and External View

Partial View Reduction Barbed Congruence

The *largest* relation over *systems*, running over the *same network* denoted by $\Gamma \models M \cong_{\text{obs}} N$, that is:

- reduction closed
- partial view barb preserving
- partial view contextual

Partial View Bisimulation: $\approx_{\text{obs}}$

- $\approx_{\text{obs}} \subseteq \cong_{\text{obs}}$
- $\cong_{\text{obs}} \subseteq \approx_{\text{obs}}$

Internal and External View

Induce Failure

- Use the process $l[\![\mathsf{kill}]\!]$
- $F^n \Leftarrow \underbrace{l_1[\![\mathsf{kill}]\!] \mid \ldots \mid l_n[\![\mathsf{kill}]\!]}_{n}$
- $\Gamma \vdash F^n$ if $\mathbf{fn}(F^n) \in \mathsf{conf}(\Gamma)$

Internal and External View

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- $\Gamma \vdash F^n$ if $\mathbf{fn}(F^n) \in \mathsf{conf}(\Gamma)$

Example

$$\text{If } \Gamma \vdash l : \mathsf{p},\ k : \mathsf{c}$$

$$\Gamma \vdash F^1 \Leftarrow k[\![\mathsf{kill}]\!]$$
$$\Gamma \not\vdash F^2 \Leftarrow l[\![\mathsf{kill}]\!] | k[\![\mathsf{kill}]\!]$$

Fault Tolerance Definition

The configuration $\Gamma \triangleright N$ is fault tolerant up to n-faults iff:

$$\forall F^n \text{ such that } \Gamma \vdash F^n \quad \text{then}$$

$$\Gamma \models N \cong_{\text{obs}} N|F^n$$

Example

If $\Gamma \vdash l : \mathrm{p},\ k_1 : \mathrm{c},\ k_2 : \mathrm{c}$

Recall

$$\mathsf{serverLoc} \Leftarrow (\nu\, \mathit{data}) \left(\begin{array}{l} l[\![\mathit{req}?(x_1, x_2).\mathrm{go}\, k_1.\mathit{data}!\langle x_1, x_2\rangle]\!] \\ \mid k_1[\![\mathit{data}?(y_1, y_2).\mathrm{go}\, l.y_2!\langle \mathbf{lookup}(y_1)\rangle]\!] \end{array} \right)$$

Then $\Gamma \triangleright \mathsf{serverLoc}$ is *not* fault tolerant up to 1-fault because

$$\Gamma \models \mathsf{serverLoc} \not\approx_{\mathsf{obs}} \mathsf{serverLoc} \mid k_1[\![\mathsf{kill}]\!]$$

Example

If $\Gamma \vdash l : \mathrm{p},\ k_1 : \mathrm{c},\ k_2 : \mathrm{c}$

Recall

$$\text{server2} \quad \Leftarrow \quad (\nu\, \mathit{data})\left(\begin{array}{l} l\left[\!\left[\mathit{req}?(x_1, x_2).(\nu \mathit{sync})\left(\begin{array}{l} \text{go}\, k_1.\mathit{data}!\langle x_1, \mathit{sync}\rangle \\ \mid \text{go}\, k_2.\mathit{data}!\langle x_1, \mathit{sync}\rangle \\ \mid \mathit{sync}?(z).x_2!\langle z\rangle \end{array}\right)\right]\!\right] \\ \\ \mid k_1[\![\mathit{data}?(y_1, y_2).\text{go}\, l.y_2!\langle \mathbf{lookup}(y_1)\rangle]\!] \\ \mid k_2[\![\mathit{data}?(y_1, y_2).\text{go}\, l.y_2!\langle \mathbf{lookup}(y_1)\rangle]\!] \end{array}\right)$$

Example

If $\Gamma \vdash l : \mathrm{p},\ k_1 : \mathrm{c},\ k_2 : \mathrm{c}$

$\Gamma \triangleright \mathrm{server}_2$ is fault tolerant up to 1-fault because

$$\Gamma \models \mathrm{server}_2 \cong_{\mathrm{obs}} \mathrm{server}_2 \mid k_1[\![\mathrm{kill}]\!]$$
$$\Gamma \models \mathrm{server}_2 \cong_{\mathrm{obs}} \mathrm{server}_2 \mid k_2[\![\mathrm{kill}]\!]$$

Example

If $\Gamma \vdash l : \mathsf{p},\ k_1 : \mathsf{c},\ k_2 : \mathsf{c}$

Recall

$$\mathsf{srvPng} \quad \Leftarrow \quad (\nu\, data)\left(\begin{array}{l} l[\![\ serv?(x,y).\mathsf{ping}\ k_1.\mathsf{go}\ k_1.data!\langle x,y\rangle \\ \qquad\qquad \lceil \mathsf{go}\ k_2.data!\langle x,y\rangle \rceil\ ]\!] \\ \mid k_1[\![data?(x,y).\mathsf{go}\ l\ .y!\langle \mathbf{lookup}(x)\rangle]\!] \\ \mid k_2[\![data?(x,y).\mathsf{go}\ l\ .y!\langle \mathbf{lookup}(x)\rangle]\!] \end{array}\right)$$

Example

If $\Gamma \vdash l : \mathrm{p},\ k_1 : \mathrm{c},\ k_2 : \mathrm{c}$

$\Gamma \triangleright$ srvPng is *not* fault tolerant up to 1-fault because

$$\Gamma \models \mathrm{srvPng} \not\approx_{\mathrm{obs}} \mathrm{srvPng} \mid k_1[\![\mathrm{kill}]\!]$$

Conclusions

- Distributed Behaviour and Partial Failure: DπF
  - Reduction Semantics
  - Sound and Complete Bisimulation
- Dependability: Fault Tolerance
  - Formal Definition
  - Bisimulation Techniques

References

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