Actors (PDCS 4)
AMST actor language syntax, semantics, join continuations

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Advantages of concurrent programs

- Reactive programming
  – User can interact with applications while tasks are running, e.g., stopping the transfer of a big file in a web browser.
- Availability of services
  – Long-running tasks need not delay short-running ones, e.g., a web server can serve an entry page while at the same time processing a complex query.
- Parallelism
  – Complex programs can make better use of multiple resources in new multi-core processor architectures, SMPs, LANs, WANs, grids, and clouds, e.g., scientific/engineering applications, simulations, games, etc.
- Controllability
  – Tasks requiring certain preconditions can suspend and wait until the preconditions hold, then resume execution transparently.

Disadvantages of concurrent programs

- Safety
  - *« Nothing bad ever happens »*
  - Concurrent tasks should not corrupt consistent state of program.
- Liveness
  - *« Anything ever happens at all »*
  - Tasks should not suspend and indefinitely wait for each other (deadlock).
- Non-determinism
  - Mastering exponential number of interleavings due to different schedules.
- Resource consumption
  - Threads can be expensive. Overhead of scheduling, context-switching, and synchronization.
  - Concurrent programs can run *slower* than their sequential counterparts even with multiple CPUs!

Overview of concurrent programming

- There are four basic approaches:
  - Sequential programming (no concurrency)
  - Declarative concurrency (streams in a functional language)
  - Message passing with active objects (Erlang, SALSA)
  - Atomic actions on shared state (Java)
- The atomic action approach is the *most difficult*, yet it is the one you will probably be most exposed to!
- But, if you have the choice, which approach to use?
  - Use the simplest approach that does the job: sequential if that is ok, else declarative concurrency if there is no observable nondeterminism, otherwise use actors and message passing.

Actors/SALSA

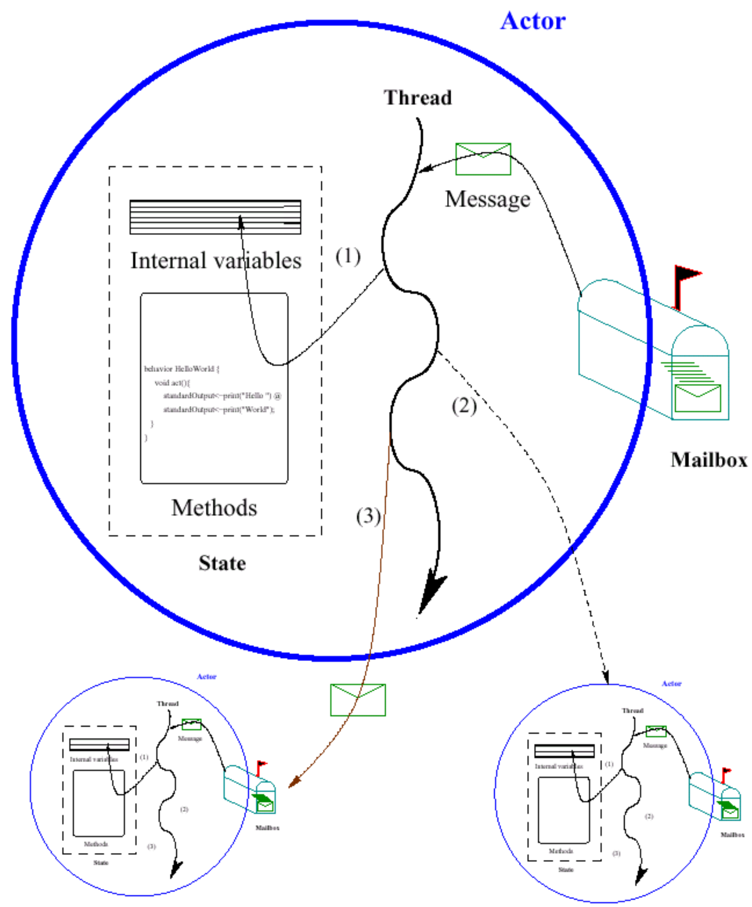
- Actor Model
  - A reasoning framework to model concurrent computations
  - Programming abstractions for distributed open systems

  G. Agha, *Actors: A Model of Concurrent Computation in Distributed Systems.* MIT Press, 1986.

  Agha, Mason, Smith and Talcott, "A Foundation for Actor Computation", *J. of Functional Programming*, 7, 1-72, 1997.

- SALSA
  - Simple Actor Language System and Architecture
  - An actor-oriented language for mobile and internet computing
  - Programming abstractions for internet-based concurrency, distribution, mobility, and coordination

  C. Varela and G. Agha, "Programming dynamically reconfigurable open systems with SALSA", *ACM SIGPLAN Notices, OOPSLA 2001,* 36(12), pp 20-34.



Agha, Mason, Smith & Talcott

1. Extend a functional language (λ-calculus + ifs and pairs) with actor primitives.

2. Define an operational semantics for actor configurations.

3. Study various notions of equivalence of actor expressions and configurations.

4. Assume fairness:
   - Guaranteed message delivery.
   - Individual actor progress.

Open Distributed Systems

- Addition of new components
- Replacement of existing components
- Changes in interconnections

Synchronous vs. Asynchronous Communication

- The π-calculus (and other process algebras such as CCS, CSP) take synchronous communication as a primitive.

- The actor model assumes asynchronous communication is *the most* primitive interaction mechanism.

Communication Medium

- In the π-calculus, channels are explicitly modeled. Multiple processes can share a channel, potentially causing interference.

- In the actor model, the communication medium is not explicit. Actors (active objects) are first-class, history-sensitive entities with an explicit identity used for communication.

Fairness

- The actor model theory assumes fair computations:
  1. Message delivery is guaranteed.
  2. Individual actor computations are guaranteed to progress.

Fairness is very useful for reasoning about equivalences of actor programs but can be hard/expensive to guarantee; in particular when distribution and failures are considered.

λ-Calculus as a Model for Sequential Computation

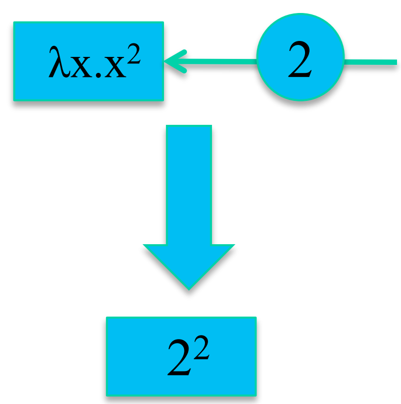
Syntax

e	::=	v	*value*
		| λv.e	*functional abstraction*
		| (e e)	*application*

Example of beta-reduction:

$(\lambda x.x^2 \quad 2)$

$\longrightarrow \quad x^2\{2/x\}$



λ-Calculus extended with pairs

- pr(x,y) — *returns a pair containing x & y*
- ispr(x) — *returns **t** if x is a pair; **f** otherwise*
- $1^{st}(pr(x,y)) = x$ — *returns the first value of a pair*
- $2^{nd}(pr(x,y)) = y$ — *returns the second value of a pair*

Actor Primitives

- `send(a,v)`
  - Sends value ***v*** to actor ***a***.
- `new(b)`
  - Creates a new actor with behavior ***b*** (a λ-calculus abstraction) and returns the identity/name of the newly created actor.
- `ready(b)`
  - Becomes ready to receive a new message with behavior ***b***.

AMST Actor Language Examples

```
b5 = rec(λy. λx.seq(send(x,5),ready(y)))
```

receives an actor name ***x*** and sends the number 5 to that actor, then it becomes ready to process new messages with the same behavior ***y***.

Sample usage:

```
send(new(b5), a)
```

A *sink,* an actor that disregards all messages:

```
sink = rec(λb. λm.ready(b))
```

Reference Cell

```
cell = rec(λb.λc.λm.
  if ( get?(m),
       seq( send(cust(m), c),
            ready(b(c)))
       if ( set?(m),
            ready(b(contents(m))),
            ready(b(c)))))
```

Using the cell:

```
let a = new(cell(0)) in seq( send(a, mkset(7)),
                             send(a, mkset(2)),
                             send(a, mkget(c)))
```

Join Continuations

Consider:

```
treeprod = rec(λf.λtree.
                if(isnat(tree),
                   tree,
                   f(left(tree))*f(right(tree))))
```

which multiplies all leaves of a tree, which are numbers.

You can do the “left” and “right” computations concurrently.

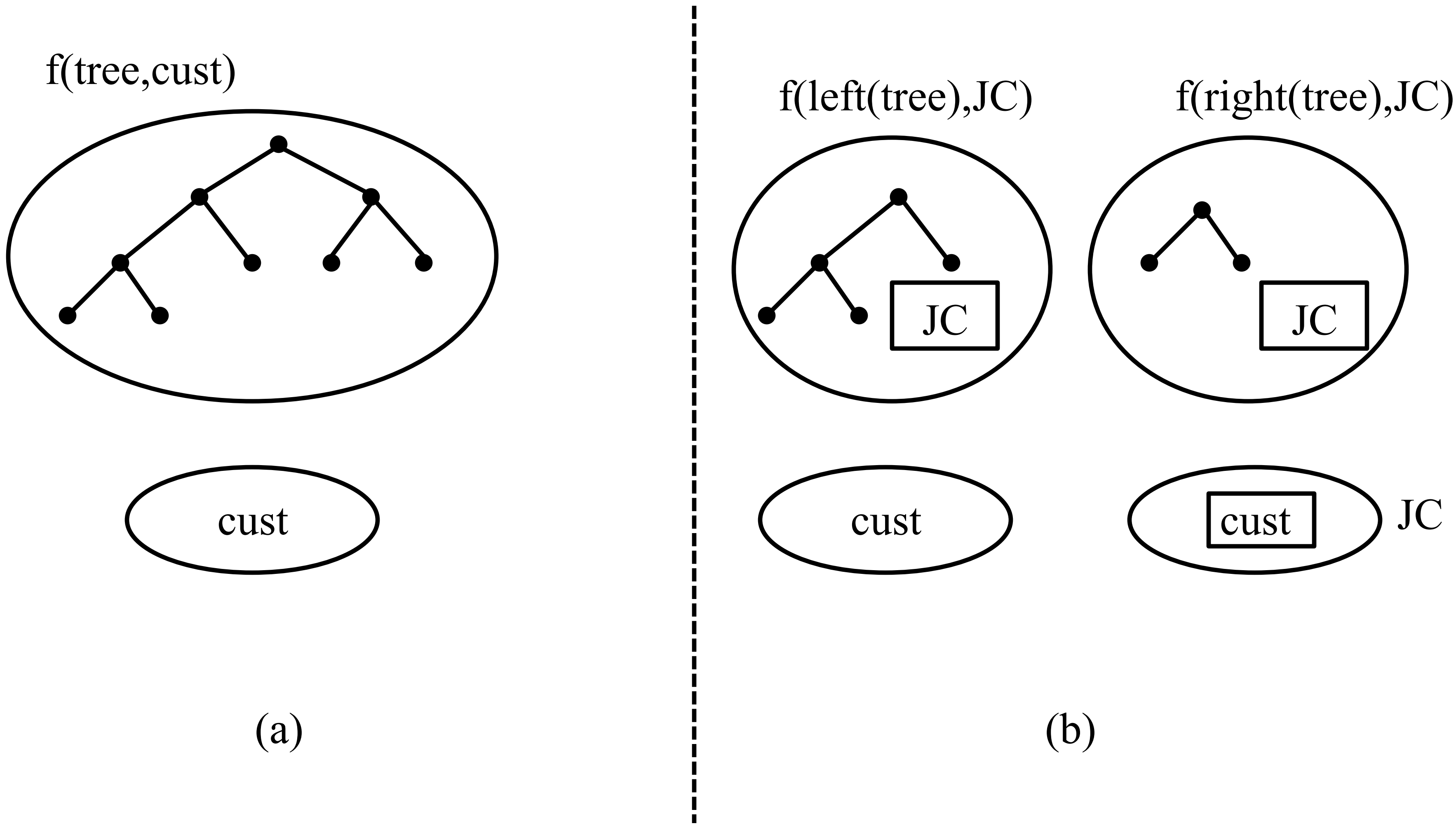
Tree Product Behavior

```
B_treeprod =
  rec(λb.λm.
      seq(if(isnat(tree(m)),
             send(cust(m),tree(m)),
             let newcust=new(B_joincont(cust(m))),
                 lp = new(B_treeprod),
                 rp = new(B_treeprod) in
             seq(send(lp,
                 pr(left(tree(m)),newcust)),
               send(rp,
                 pr(right(tree(m)),newcust)))),
         ready(b)))
```

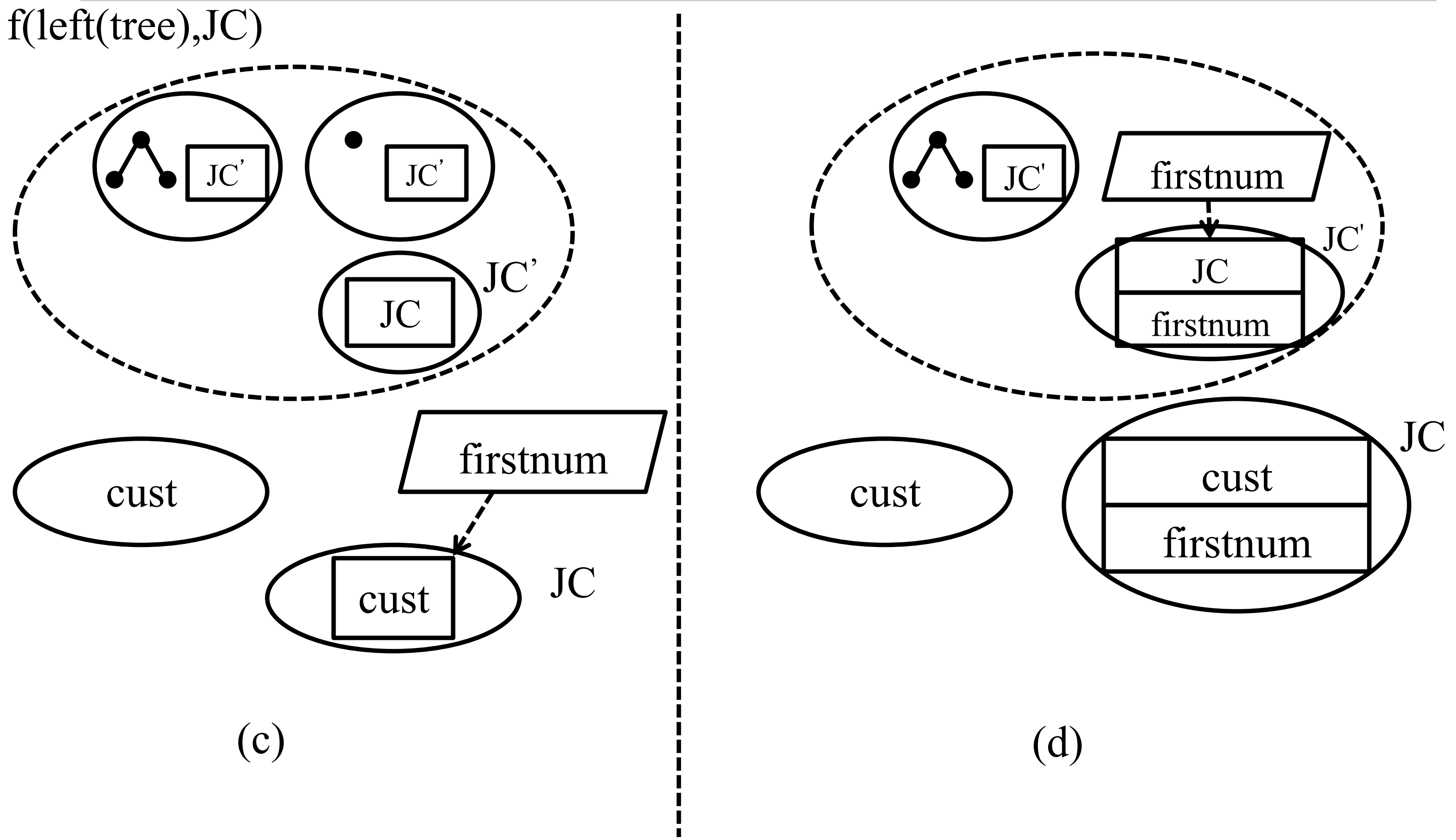
Tree Product (continued)

```
Bjoincont =
  λcust.λfirstnum.ready(λnum.
            seq(send(cust,firstnum*num),
                     ready(sink)))
```

Sample Execution



Sample Execution



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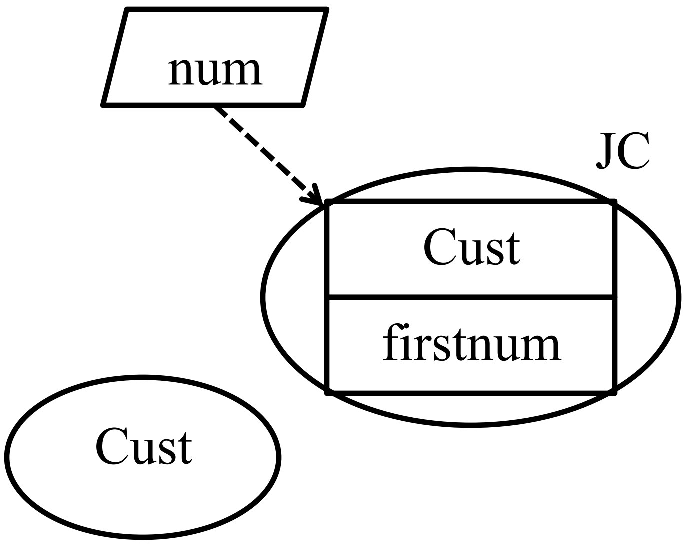

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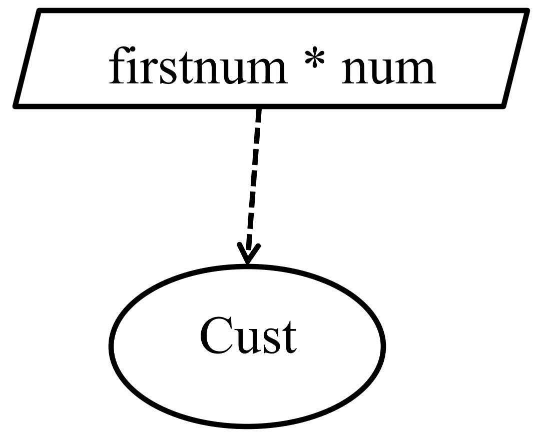

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Operational Semantics for AMST Actor Language

- Operational semantics of actor model as a labeled transition relationship between actor configurations.

- Actor configurations model open system components:

  – Set of individually named actors

  – Messages "en-route"

Actor Configurations

$$\mathbf{k} = \boldsymbol{\alpha} \,||\, \boldsymbol{\mu}$$

$\boldsymbol{\alpha}$ is a function mapping actor names (represented as free variables) to actor states.

$\boldsymbol{\mu}$ is a multi-set of messages "en-route."

Syntactic restrictions on configurations

Given A = Dom(α):

- If a in A, then fv(α(a)) is a subset of A.

- If <a <= v> in μ, then {a} U fv(v) is a subset of A.

Reduction contexts and redexes

Consider the expression:

`e = send(new(b5), a)`

- The redex `r` represents the next sub-expression to evaluate in a left-first call-by-value evaluation strategy.
- The reduction context `R` (or *continuation*) is represented as the surrounding expression with a *hole* replacing the redex.

`send(new(b5), a) = send(□,a)▶new(b5)◀`

`e = R▶r◀` where

`R = send(□,a)`

`r = new(b5)`

Labeled Transition Relation

$$\frac{e \rightarrow_\lambda e'}{\alpha, [\mathsf{R} \blacktriangleright e \blacktriangleleft]_a \parallel \mu \xrightarrow{[\mathbf{fun}:a]} \alpha, [\mathsf{R} \blacktriangleright e' \blacktriangleleft]_a \parallel \mu}$$

$$\alpha, [\mathsf{R} \blacktriangleright \mathtt{new}(b) \blacktriangleleft]_a \parallel \mu \xrightarrow{[\mathbf{new}:a,a']} \alpha, [\mathsf{R} \blacktriangleright a' \blacktriangleleft]_a, [\mathtt{ready}(b)]_{a'} \parallel \mu$$

a' fresh

$$\alpha, [\mathsf{R} \blacktriangleright \mathtt{send}(a', v) \blacktriangleleft]_a \parallel \mu \xrightarrow{[\mathbf{snd}:a]} \alpha, [\mathsf{R} \blacktriangleright \mathtt{nil} \blacktriangleleft]_a \parallel \mu \uplus \{\langle a' \Leftarrow v \rangle\}$$

$$\alpha, [\mathsf{R} \blacktriangleright \mathtt{ready}(b) \blacktriangleleft]_a \parallel \{\langle a \Leftarrow v \rangle\} \uplus \mu \xrightarrow{[\mathbf{rcv}:a,v]} \alpha, [b(v)]_a \parallel \mu$$

Exercises

37. Write
    ```
    get?
    cust
    set?
    contents
    mkset
    mkget
    ```
    to complete the reference cell example in the AMST actor language.
38. Modify the **`cell`** behavior to notify a customer when the cell value has been updated.
39. PDCS Exercise 4.6.6 (page 77).
40. PDCS Exercise 4.6.7 (page 78).