fwo Research Foundation Flanders
Opening new horizons

Multiverse Debugging

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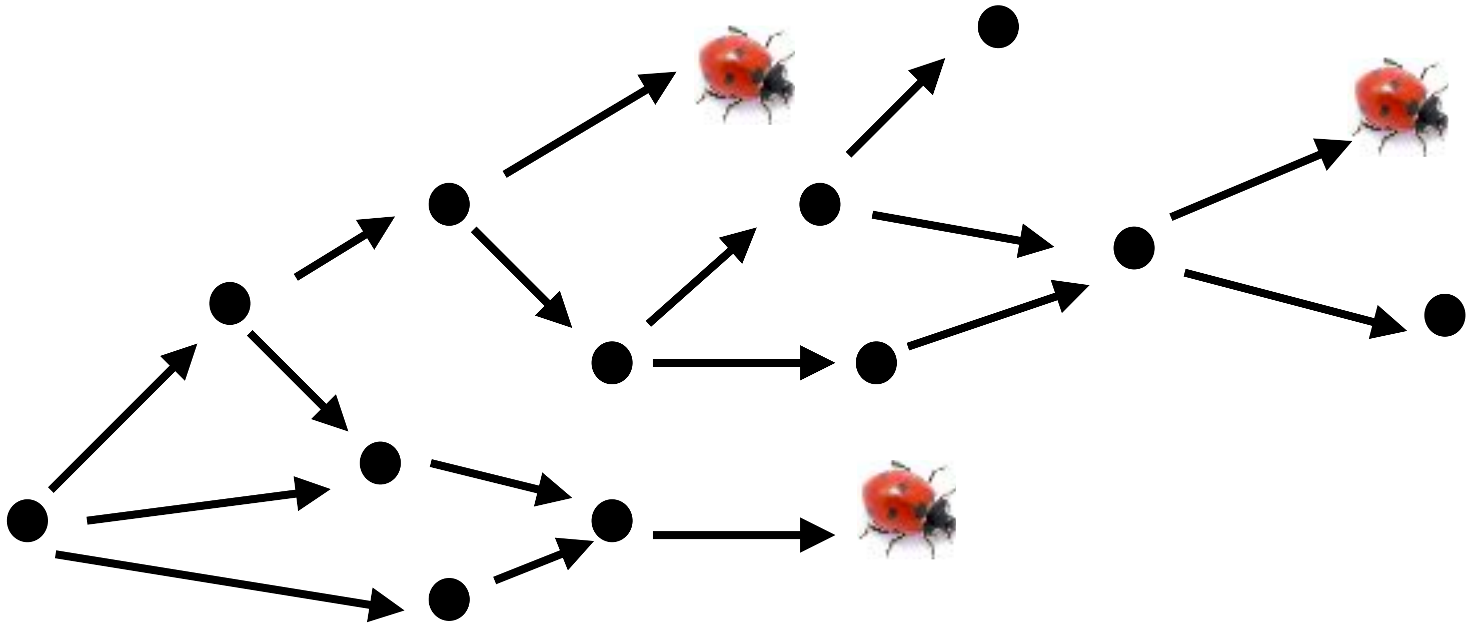
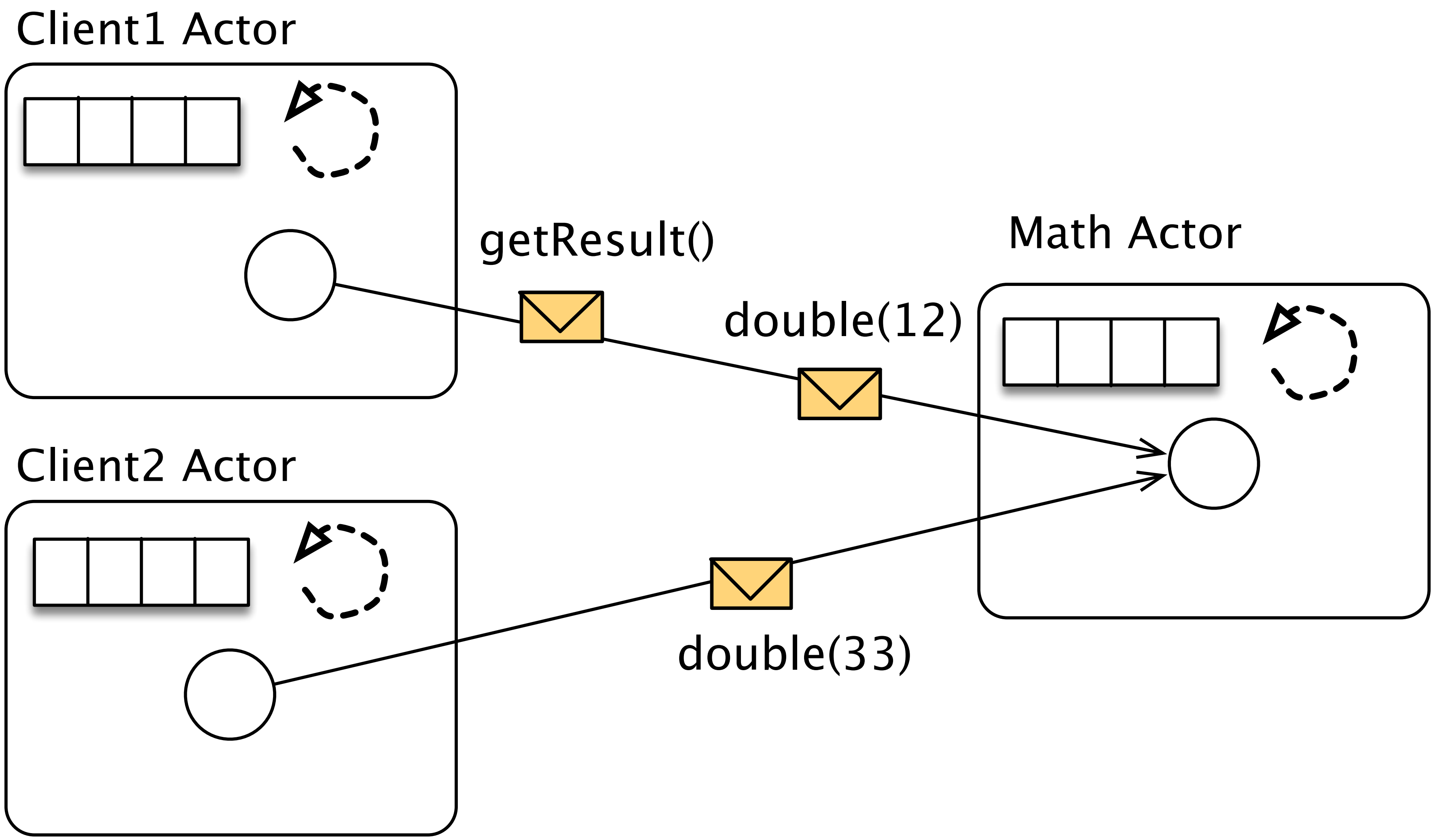
Goal

- To build a debugger for **non-deterministic programs** that
  - is probe-effect free, and
  - is able to explore the space of all possible bugs



Running Example



Running Example in AmbientTalk

```
def makeMath() {
    actor:{
        def result := 0;
        def double(x){result := x+x};
        def getResult(){result};
    }
};
def makeClient1(math){
    actor:{ |math|
        def start(){
                math<-double(12);
                when: math<-getResult()@FutureMessage becomes: {|res|
                   system.println(res);
                }}}
};
def makeClient2(math){
    actor: { |math|
        def start(){ math<-double(33) }}
};
def math := makeMath();
def client1 := makeClient1(math);
def client2 := makeClient2(math);
client1<-start();
client2<-start();
```

Bad Message Interleaving

```
def makeMath() {
    actor:{
        def result := 0;
        def double(x){result := x+x};
        def getResult(){result};
    }
};
```

Faulty Interleaving	Correct Interleaving	Correct Interleaving
client 1 - double(12)	client 1 - double(12)	client 2 - double(33)
client 2 - double(33)	client 1 - getResult() -> 24	client 1 - double(12)
client 1 - getResult() -> 66	client 2 - double(33)	client 1 - getResult() -> 24

time ↓

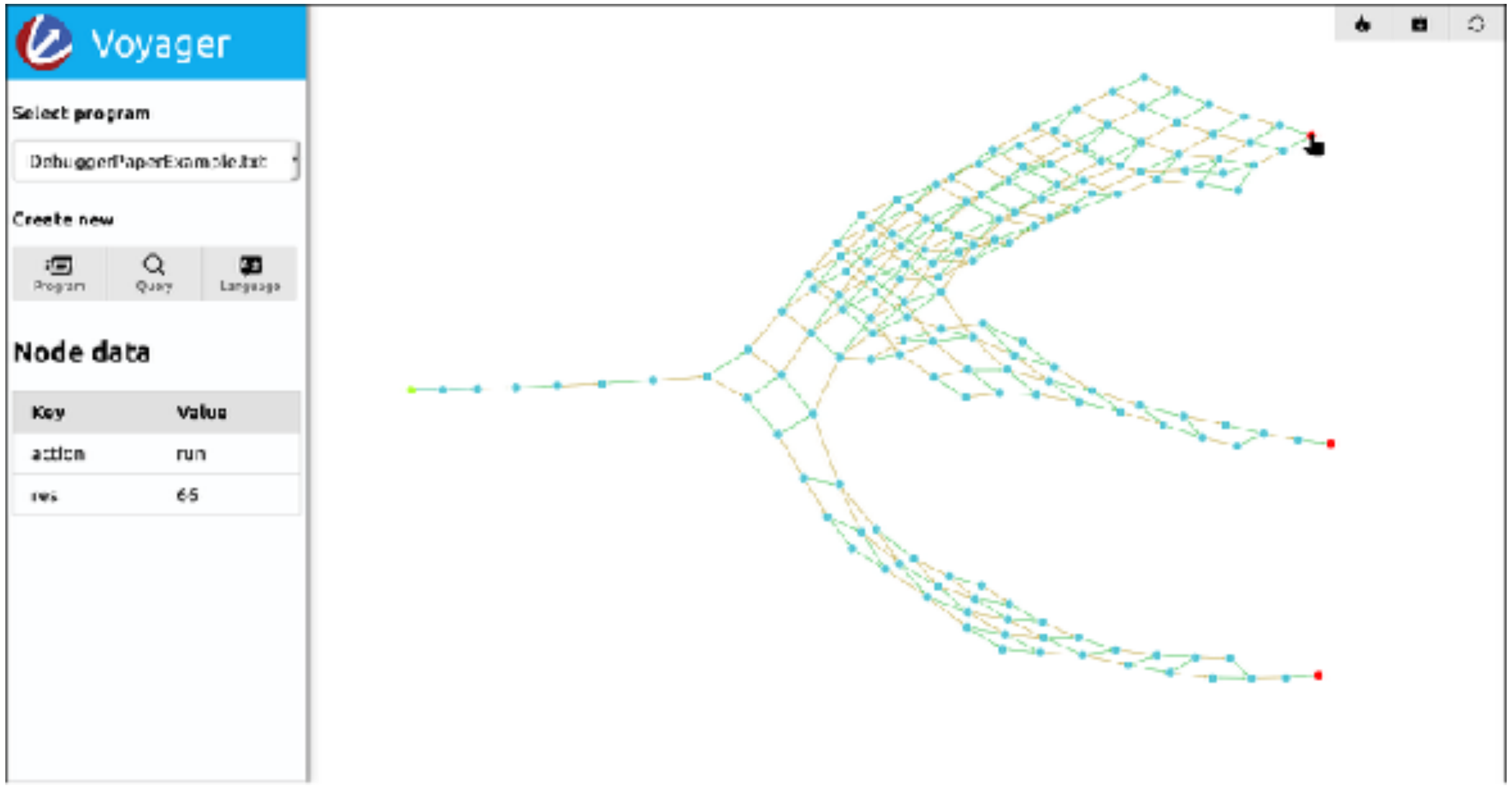
Carmen Torres Lopez, Stefan Marr, Elisa Gonzalez Boix, Hanspeter Mössenböck. A Study of Concurrency Bugs and Advanced Development Support for Actor-based Programs. Programming with Actors 2018: 155-185

Multiverse Debugging

Properties:

1. Observe *all* possible paths of the program execution

2. One step leads to a possible set of *universes*, i.e. paths of execution



Select program

DebuggerPaperExample.txt

Node data

Key	Value
action	run
res	65

Carmen Torres Lopez, Robbert Gurdeep Sigh, Stefan Marr, Elisa Gonzalez Boix, Christophe Scholliers. Multiverse Debugging: Non-deterministic Debugging for Non-deterministic Programs. To Appear in ECOOP 2019

Multiverse Debugging Recipe

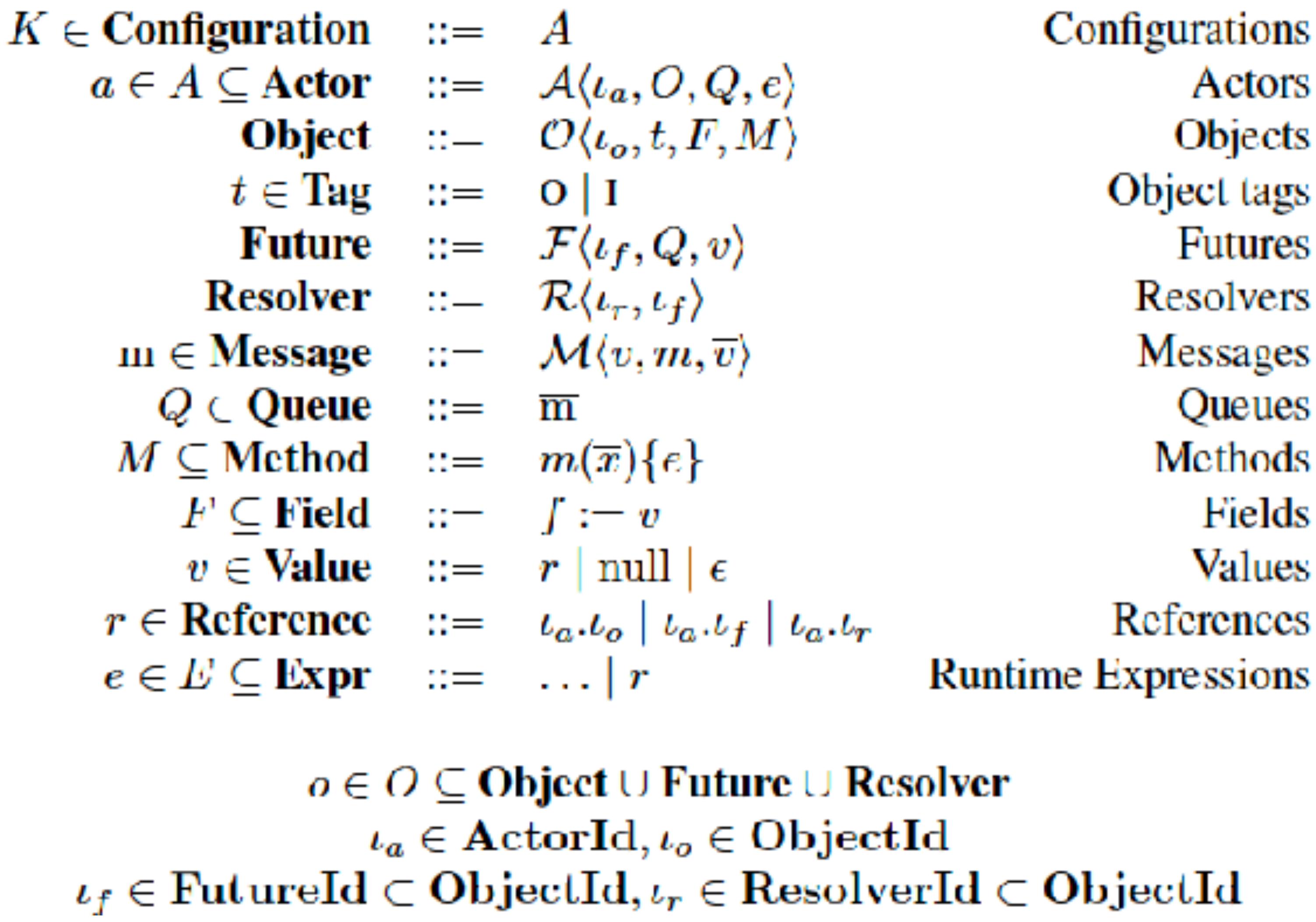
1. Operational semantics of the **non-deterministic base language**.

2. Operational semantics of the **debugger** in terms of the base-level semantics.

- **Configuration** that a debugger needs to keep track of in order to debug a base level program (including the base level semantics).
- **Debugging operations** of the debugger, in terms of the base-level semantics.

Step 1

Featherweight AmbientTalk



$K \in \mathbf{Configuration}$	$::=$	A	Configurations
$a \in A \subseteq \mathbf{Actor}$	$::=$	$\mathcal{A}\langle \iota_a, O, Q, e \rangle$	Actors
$\mathbf{Object}$	$::=$	$\mathcal{O}\langle \iota_o, t, F, M \rangle$	Objects
$t \in \mathbf{Tag}$	$::=$	$\textsc{o} \mid \textsc{i}$	Object tags
$\mathbf{Future}$	$::=$	$\mathcal{F}\langle \iota_f, Q, v \rangle$	Futures
$\mathbf{Resolver}$	$::=$	$\mathcal{R}\langle \iota_r, \iota_f \rangle$	Resolvers
$m \in \mathbf{Message}$	$::=$	$\mathcal{M}\langle v, m, \overline{v} \rangle$	Messages
$Q \subseteq \mathbf{Queue}$	$::=$	$\overline{m}$	Queues
$M \subseteq \mathbf{Method}$	$::=$	$m(\overline{x})\{e\}$	Methods
$F \subseteq \mathbf{Field}$	$::=$	$f := v$	Fields
$v \in \mathbf{Value}$	$::=$	$r \mid \mathtt{null} \mid \epsilon$	Values
$r \in \mathbf{Reference}$	$::=$	$\iota_a.\iota_o \mid \iota_a.\iota_f \mid \iota_a.\iota_r$	References
$e \in E \subseteq \mathbf{Expr}$	$::=$	$\ldots \mid r$	Runtime Expressions

$$o \in O \subseteq \mathbf{Object} \cup \mathbf{Future} \cup \mathbf{Resolver}$$

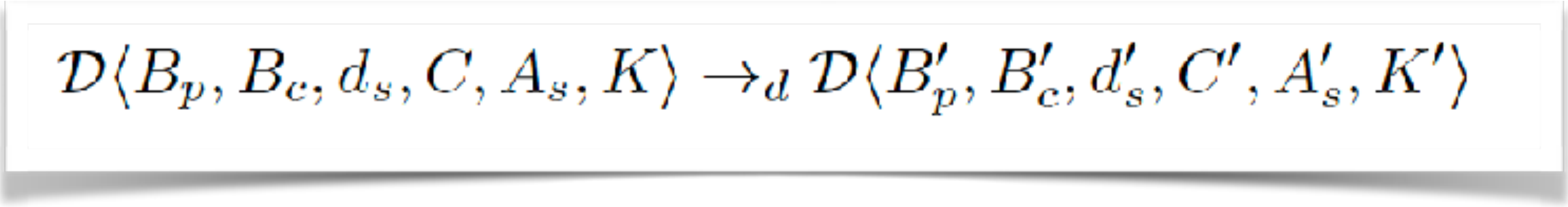
$$\iota_a \in \mathbf{ActorId}, \iota_o \in \mathbf{ObjectId}$$

$$\iota_f \in \mathbf{FutureId} \subset \mathbf{ObjectId}, \iota_r \in \mathbf{ResolverId} \subset \mathbf{ObjectId}$$

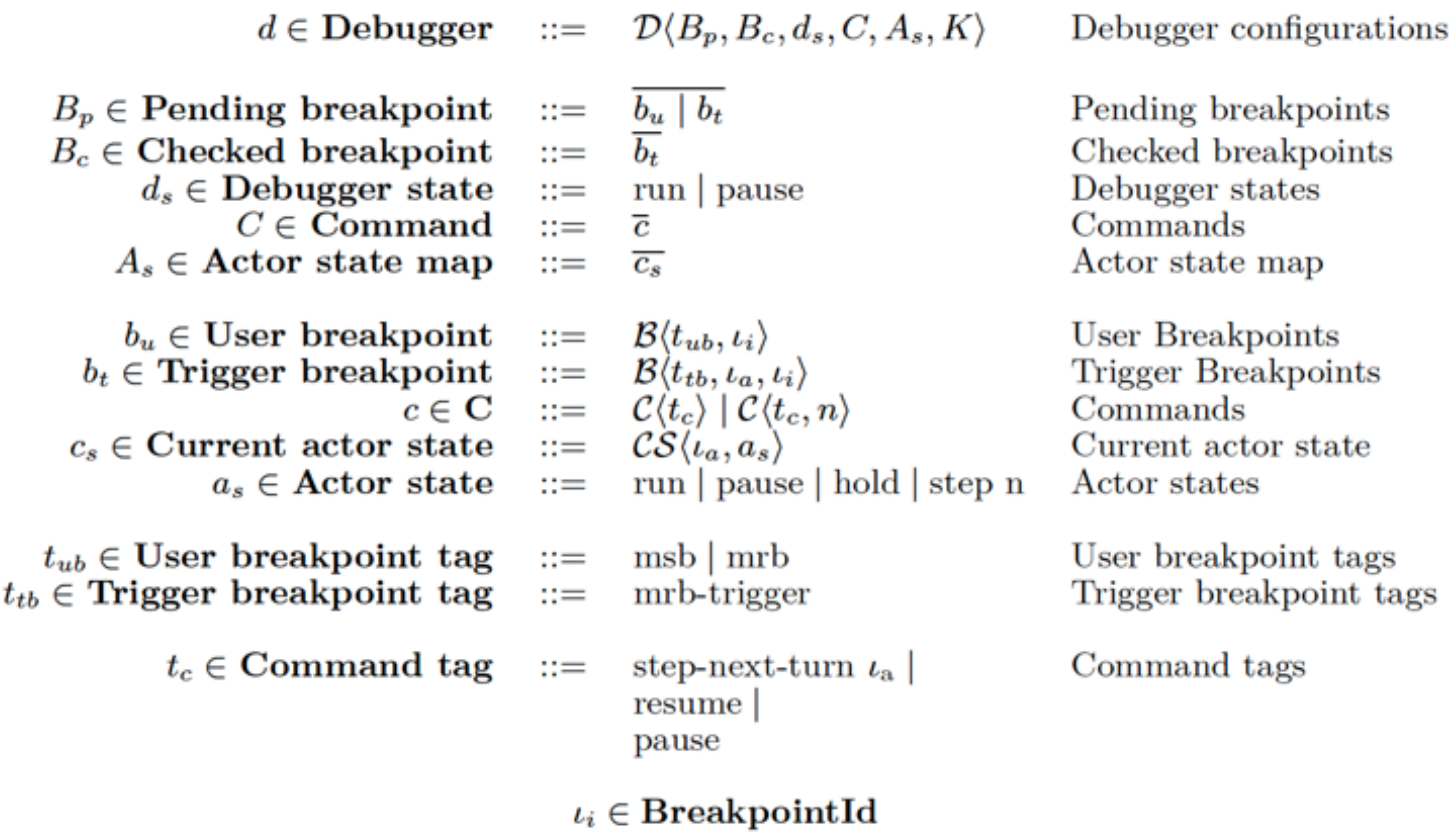
Van Cutsem T., Gonzalez Boix E., Scholliers C, Lombide Carreton A., Harnie D., Pinte K., and De Meuter W., 2014. *AmbientTalk: programming responsive mobile peer-to-peer applications with actors*. Computer Languages, Systems and Structures 40, 3–4 (2014), 112–136.

Step 2

Voyager



$$\mathcal{D}\langle B_p, B_c, d_s, C, A_s, K\rangle \rightarrow_d \mathcal{D}\langle B_p', B_c', d_s', C', A_s', K'\rangle$$



$d \in$ **Debugger**	::=	$\mathcal{D}\langle B_p, B_c, d_s, C, A_s, K\rangle$	Debugger configurations
$B_p \in$ **Pending breakpoint**	::=	$\overline{b_u \mid b_t}$	Pending breakpoints
$B_c \in$ **Checked breakpoint**	::=	$\overline{b_t}$	Checked breakpoints
$d_s \in$ **Debugger state**	::=	run | pause	Debugger states
$C \in$ **Command**	::=	$\overline{c}$	Commands
$A_s \in$ **Actor state map**	::=	$\overline{c_s}$	Actor state map
$b_u \in$ **User breakpoint**	::=	$\mathcal{B}\langle t_{ub}, \iota_i\rangle$	User Breakpoints
$b_t \in$ **Trigger breakpoint**	::=	$\mathcal{B}\langle t_{tb}, \iota_a, \iota_i\rangle$	Trigger Breakpoints
$c \in$ **C**	::=	$\mathcal{C}\langle t_c\rangle \mid \mathcal{C}\langle t_c, n\rangle$	Commands
$c_s \in$ **Current actor state**	::=	$\mathcal{CS}\langle \iota_a, a_s\rangle$	Current actor state
$a_s \in$ **Actor state**	::=	run | pause | hold | step n	Actor states
$t_{ub} \in$ **User breakpoint tag**	::=	msb | mrb	User breakpoint tags
$t_{tb} \in$ **Trigger breakpoint tag**	::=	mrb-trigger	Trigger breakpoint tags
$t_c \in$ **Command tag**	::=	step-next-turn ι_a | resume | pause	Command tags

$\iota_i \in$ **BreakpointId**

Running Example in Voyager

```
(
  ()                                    ; Pending breakpoints
  ()                                    ; Checked breakpoints
  run                                   ; Debugger state
  ()
  ()                                    ; Commands (user interaction)
  ((client1 run))                       ; Actor map
  ((actor                               ; Base language term
    client1
    ()
    ()
    (let (math (actor
         (field result 0)
         (method double x (set! (this $ result) (+ x x)))
         (method result p (this $ result))))
    in
    (let (client2 (actor
            (method start math (send math double (33) c2-double-to-math))))
    in
    (let (a (send client2 start (math) c1-start-to-c2)) in
    (let (b  (send math double (12) c1-double-to-math)) in
    (let (x_f x_r) future in
    (let (x_l (
          let (some-var 5) in
          (object (method apply x ((x_r $ resolve-mu) x))))
         ) in
    (let (var (send (let (x_f1 x_r1) future in
    (let (var (send math result (0 x_r1) c1-result-to-math)) in x_f1))
                        register-mu (x_l) c1-result-to-math)) in x_f)))))))
  ))
)
```

Demo

https://github.com/chscholl/GraphRedex/blob/artefact/ECOOP2019/Publications/ECOOP2019/README.md

Voyager available at https://redex.ugent.be/debugger.html

Conclusion

"Non-deterministic programs require non-deterministic tools"

- A new exploration path in debugging with many challenges to tackle:
    - state explosion
    - multiverse breakpoint & stepping operations
    - novel visualisations