PARALLEL GESTURE RECOGNITION WITH SOFT REAL-TIME GUARANTEES

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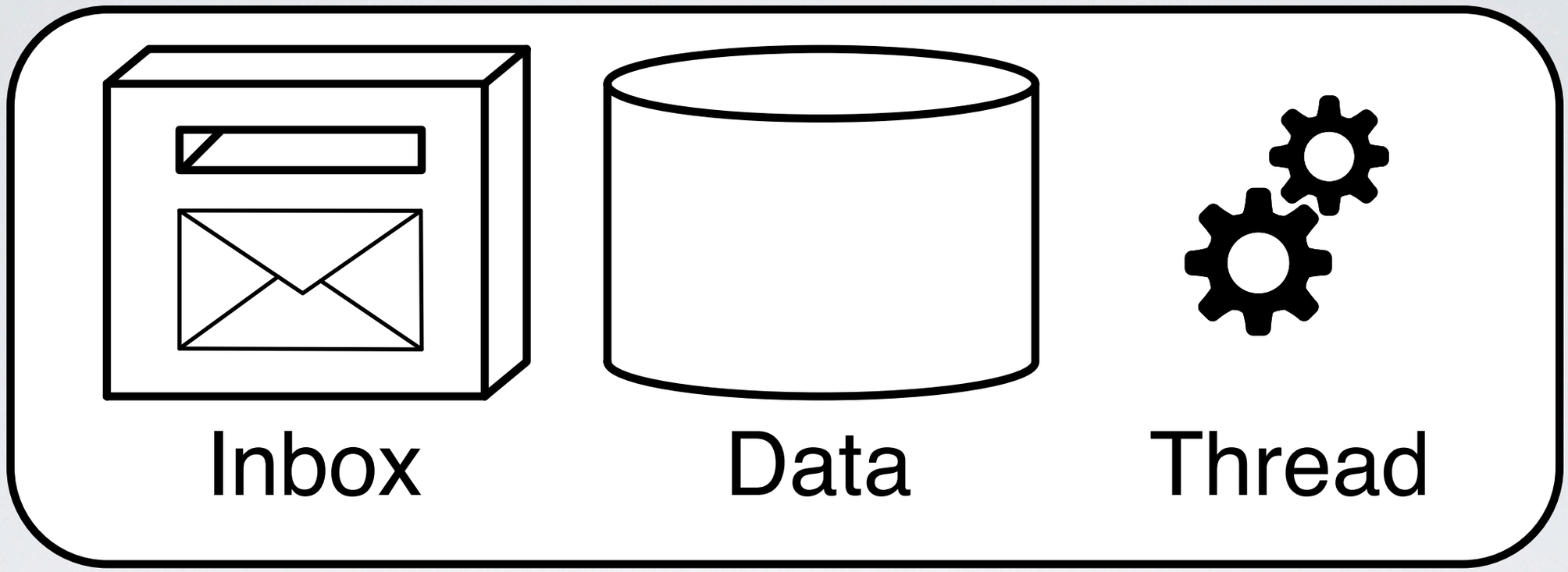
SITUATING WITHIN THE ACTOR CONTEXT



Asynchronous, message passing interoperation

Private state

Own thread of control

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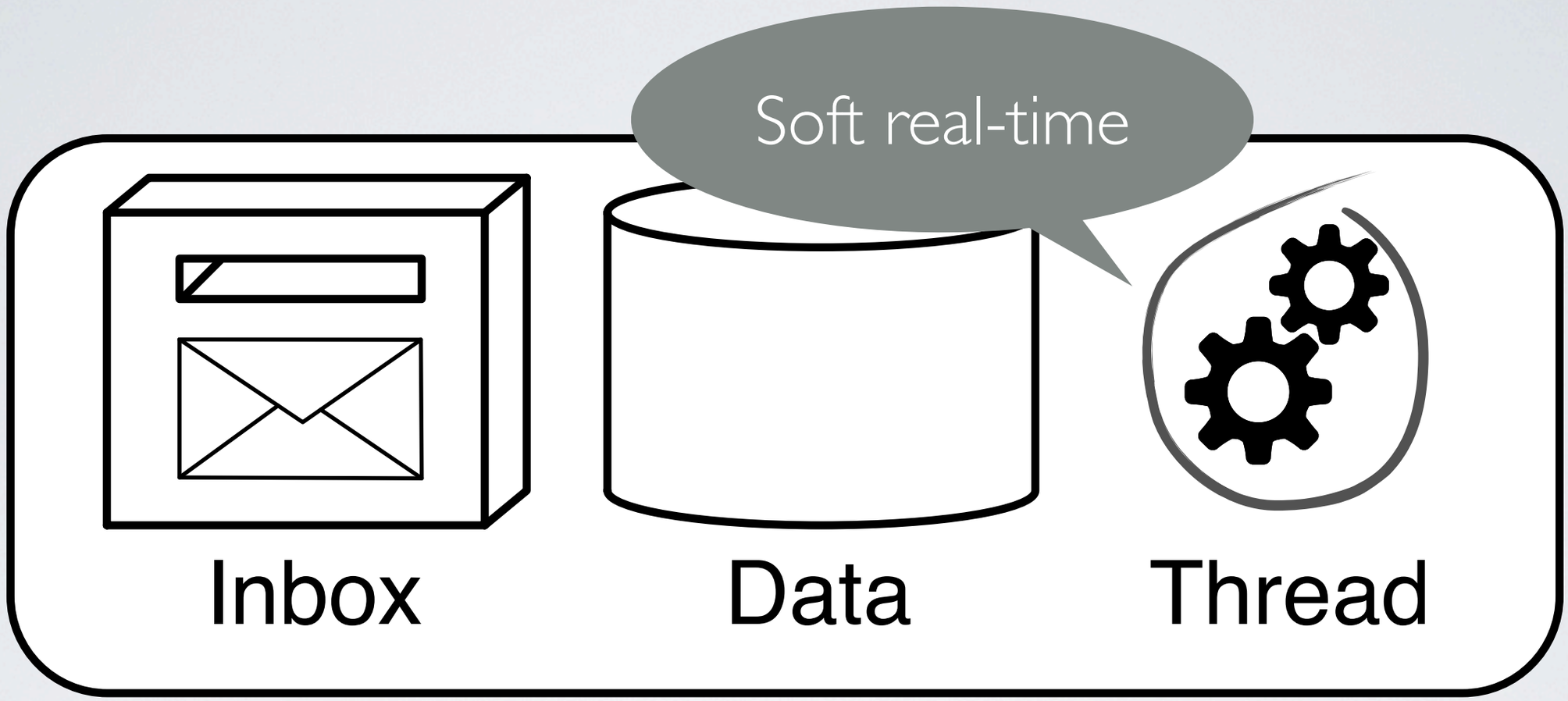

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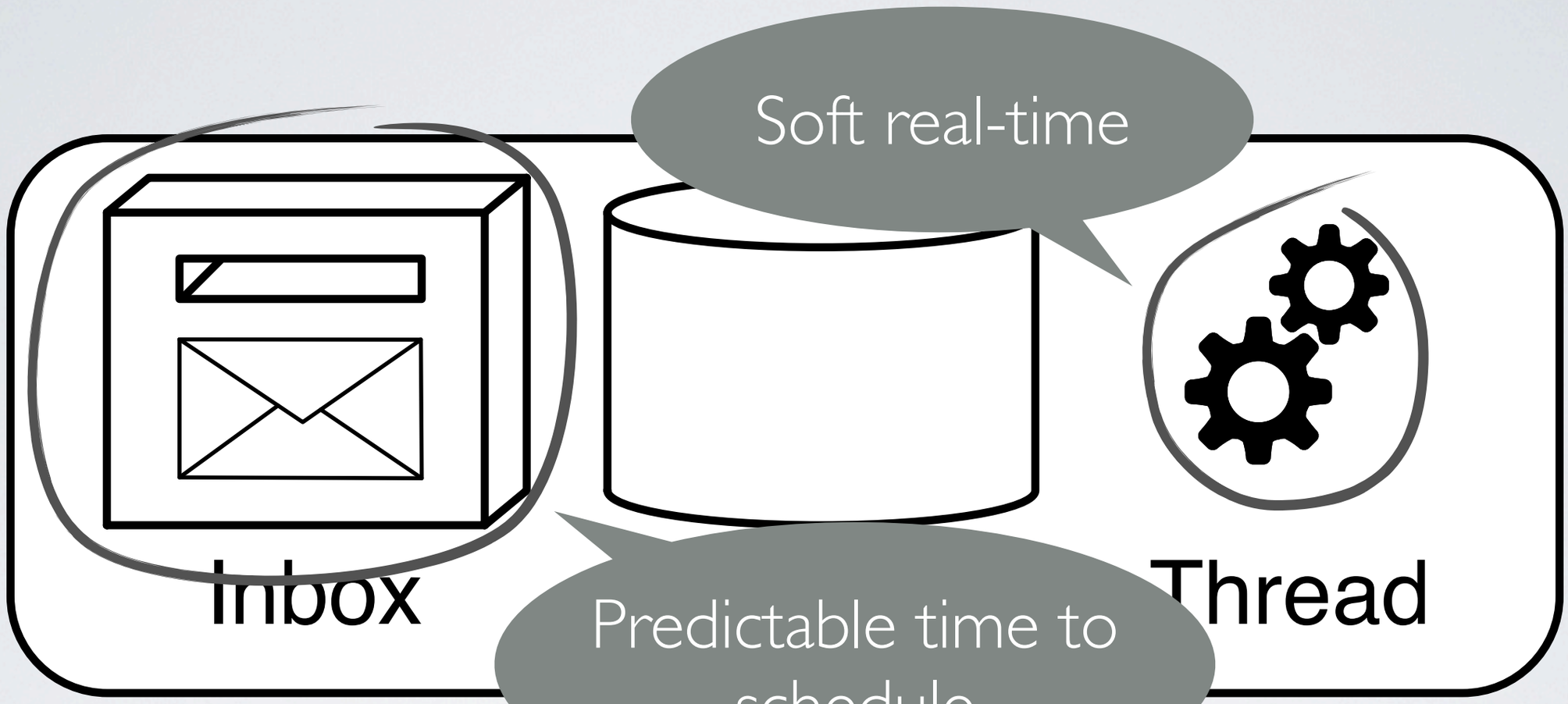

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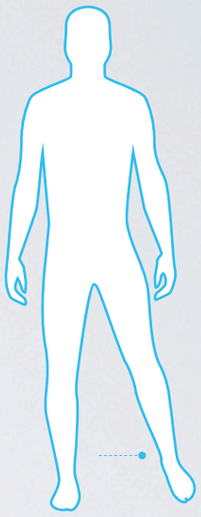
Own thread of control

USE CASE: GESTURE RECOGNITION

What we get:

Coordinates of touches and releases

Positions of joints in time



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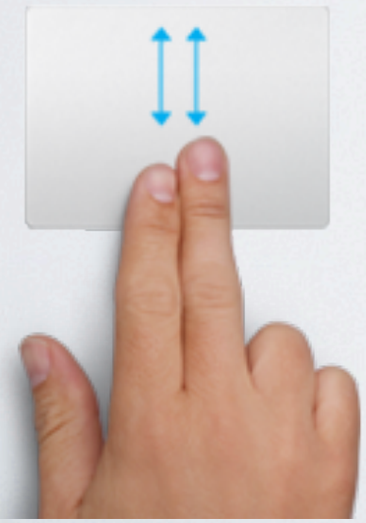

"A two-finger drag at time t"

"User u lifted his right leg, with his hands in his sides"

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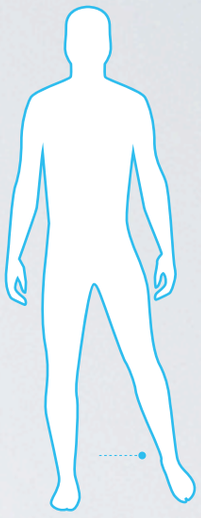

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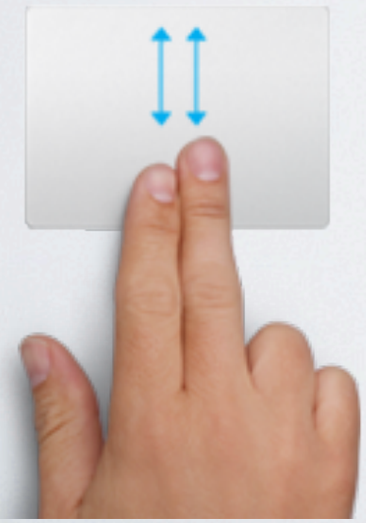

"A two-finger drag at time t"

"User u lifted his right leg, with his hands in his sides"

USE CASE: APPROACH

```
/*************************************************************************
 *
 * grail - Gesture Recognition And Instantiation Library
 *
 * Copyright (C) 2010 Canonical Ltd.
 * Copyright (C) 2010 Henrik Rydberg <rydberg@bitmath.org>
 *
 * This program is free software: you can redistribute it and/or modify it
 * under the terms of the GNU General Public License as published by the
 * Free Software Foundation, either version 3 of the License, or (at your
 * option) any later version.
 *
 * This program is distributed in the hope that it will be useful, but
 * WITHOUT ANY WARRANTY; without even the implied warranty of
 * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the GNU
 * General Public License for more details.
 *
 * You should have received a copy of the GNU General Public License along
 * with this program.  If not, see <http://www.gnu.org/licenses/>.
 *
 *************************************************************************/

#include "grail-recognizer.h"
#include <math.h>
#include <stdio.h>

static const int getype[DIM_TOUCH + 1] = {
                0,
                0,
                GRAIL_TYPE_PINCH2,
                GRAIL_TYPE_PINCH3,
                GRAIL_TYPE_PINCH4,
                GRAIL_TYPE_PINCH5,
};

static const int fm_mask = 0x04;

static void set_props(const struct gesture_inserter *gin,
                      struct combo_model *s,
                      const struct move_model *m,
                      const struct utouch_frame *frame)
{
                s->prop[GRAIL_PROP_PINCH_DR] = gin->scale_r * m->fm[FM_R].action_delta;
                s->prop[GRAIL_PROP_PINCH_VR] = gin->scale_r * m->fm[FM_R].velocity;
                s->prop[GRAIL_PROP_PINCH_R] = gin->scale_r * m->fm[FM_R].value;
                s->nprop = 3;
                s->nprop += gin_add_contact_props(gin, s->prop + s->nprop, frame);
}

int gru_pinch(struct grail *ge,
              const struct utouch_frame *frame)
{
                struct gesture_recognizer *gru = ge->gru;
                struct combo_model *state = &gru->pinch;
                struct move_model *move = &gru->move;
                int mask = state->active ? (move->active & fm_mask) : fm_mask;
                if (!move->multi && !move->single) {
                                if (state->active) {
                                                gru_end(ge, state->gid, move,
                    state->prop, state->nprop);
                                                state->active = 0;
                                }
                                return 0;
                }
                if ((move->timeout & fm_mask) == fm_mask) {
                                if (state->active) {
                                                gin_gid_discard(ge, state->gid);
                                                state->active = 0;
                                }
                                return 0;
                }
                if (!(move->tickle & mask))
                                return 0;
                if (!state->active) {
                                int type = getype[move->ntouch];
                                if (!type)
                                                return 0;
                                state->gid = gin_gid_begin(ge, type, PRIO_GESTURE, frame);
                                state->active = 1;
                }
                if (!(move->active & fm_mask))
                                return 0;
                set_props(ge->gin, state, move, frame);
                gru_event(ge, state->gid, move, state->prop, state->nprop);
                return 1;
}

int gru_winpinch(struct grail *ge,
                 const struct utouch_frame *frame)
{
                struct gesture_recognizer *gru = ge->gru;
                struct combo_model *state = &gru->winpinch;
                struct move_model *move = &gru->move;
                int mask = state->active ? (move->active & fm_mask) : fm_mask;
                if (!move->multi) {
                                if (state->active && out_of_bounds(state, move)) {
                                                gru_end(ge, state->gid, move,
                    state->prop, state->nprop);
                                                state->active = 0;
                                }
                                return 0;
                }
                if ((move->timeout & fm_mask) == fm_mask) {
                                if (state->active) {
                                                gin_gid_discard(ge, state->gid);
                                                state->active = 0;
                                }
                                return 0;
                }
                if (!(move->tickle & mask))
                                return 0;
                if (!state->active) {
                                if (move->ntouch == 4) {
                                                state->gid = gin_gid_begin(ge,
GRAIL_TYPE_MPINCH,
                                                PRIO_META, frame);
                                                state->mintouch = 2;
                                                state->maxtouch = 4;
                                                state->active = 1;
                                } else if (move->ntouch == 3) {
                                                state->gid = gin_gid_begin(ge,
GRAIL_TYPE_EPINCH,
                                                PRIO_ENV, frame);
                                                state->mintouch = 2;
                                                state->maxtouch = 3;
                                                state->active = 1;
                                } else {
                                                return 0;
                                }
                }
                if (!(move->active & fm_mask))
                                return 0;
                set_props(ge->gin, state, move, frame);
                gru_event(ge, state->gid, move, state->prop, state->nprop);
                return 1;
}
```

Approaches:

- Imperative
  - Cumbersome
  - Error-prone
- Machine Learning
  - Learning phase
  - Debuggability?!
- Declarative

USE CASE: APPROACH

```
(defrule pinchGesture
 (FingerMoved (startPoint ?sIndex)
              (endPoint ?eIndex)
              (timestamp ?tIndex)
              (duration ?deltaTIndex)
              (finger "index"))
 (FingerMoved (startPoint ?sThumb)
              (endPoint ?eThumb)
              (timestamp ?tThumb)
              (duration ?deltaTThumb)
              (finger "thumb"))
 (test (< (euclideanDistance ?eIndex ?eThumb)
          (euclideanDistance ?sIndex ?sThumb)))
 (test (overlapping ?tIndex ?tThumb
                    ?durIndex ?durThumb))
=>
 (reactToPinchAt ?sIndex ?tIndex)))
```

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- Declarative

USE CASE: THE RETE ALGORITHM

Declarative approach

Algorithms such as Rete,
Lana, Leaps, GenTrie, ...

```
; Detect Tap gesture
(defrule detectTap
     (Touch (location ?startLoc) (timestamp ?t1))
     (Release (locaction ?startLoc) (timestamp ?t2))
     (test (< (abs (- ?t1 ?t2)) MAX_DELAY))
=>
     (reactToTapAt ?startLoc))

; Detect left swipe gesture
(defrule detectLeftSwipe
     (Touch (location ?startLoc) (timestamp ?t1))
     (Release (locaction ?endLoc) (timestamp ?t2))
     (test (< (abs (- ?t1 ?t2)) MAX_DELAY))
     (test (toTheLeftOf ?endLoc ?startLoc))
=>
     (reactToSwipe))
```

USE CASE: THE RETE ALGORITHM

Declarative approach

Algorithms such as Rete,
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- Among fastest sequential algorithms
- Transforms rules into DAG
- Caches partial matches

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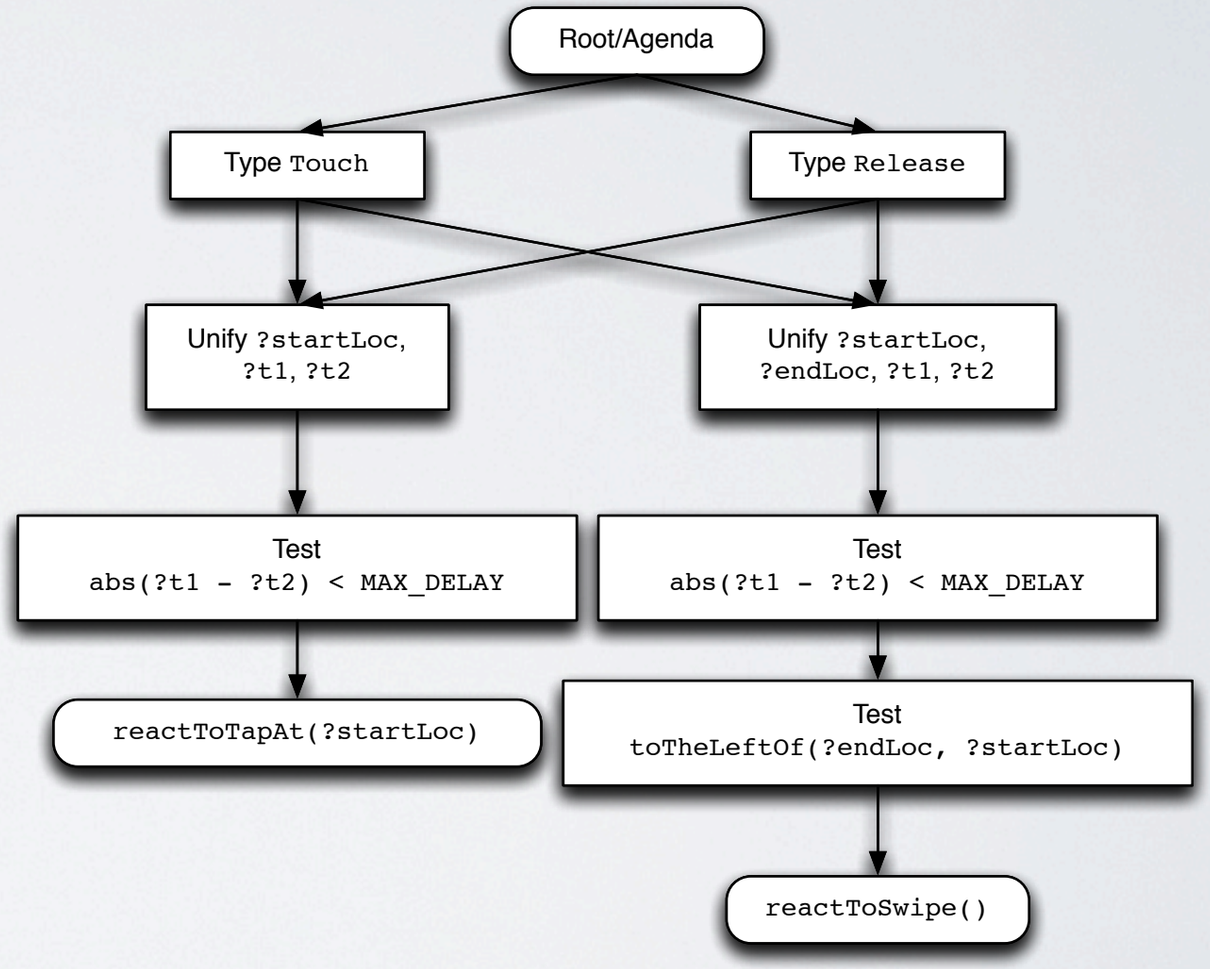
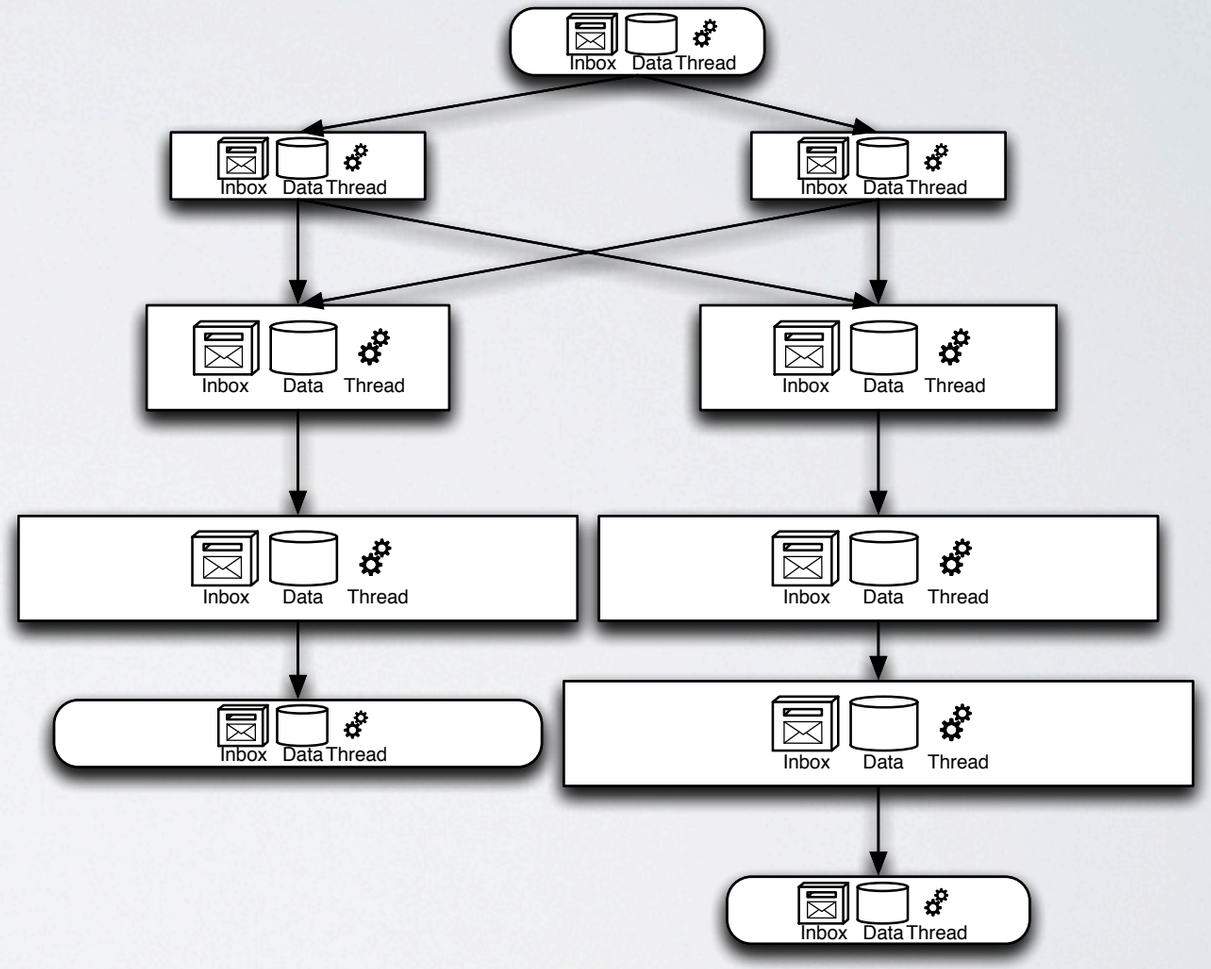


USE CASE: THE RETE ALGORITHM

Declarative approach

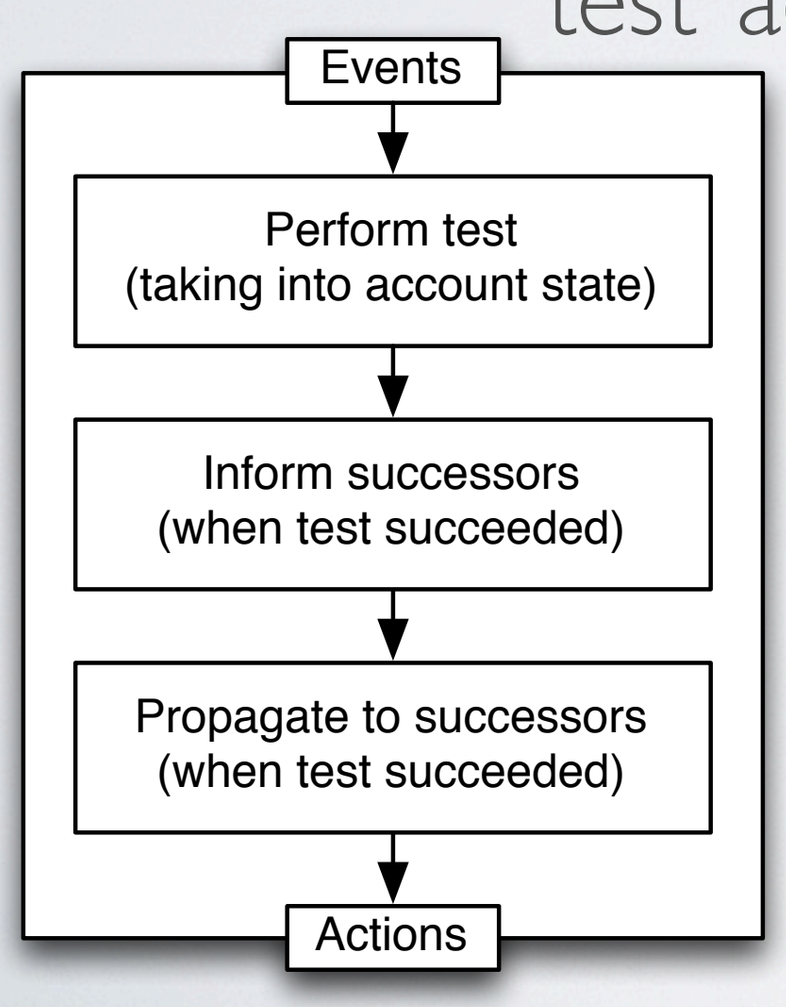
Algorithms such as Rete,
~~Lana, Leaps, GenTrie~~, ...

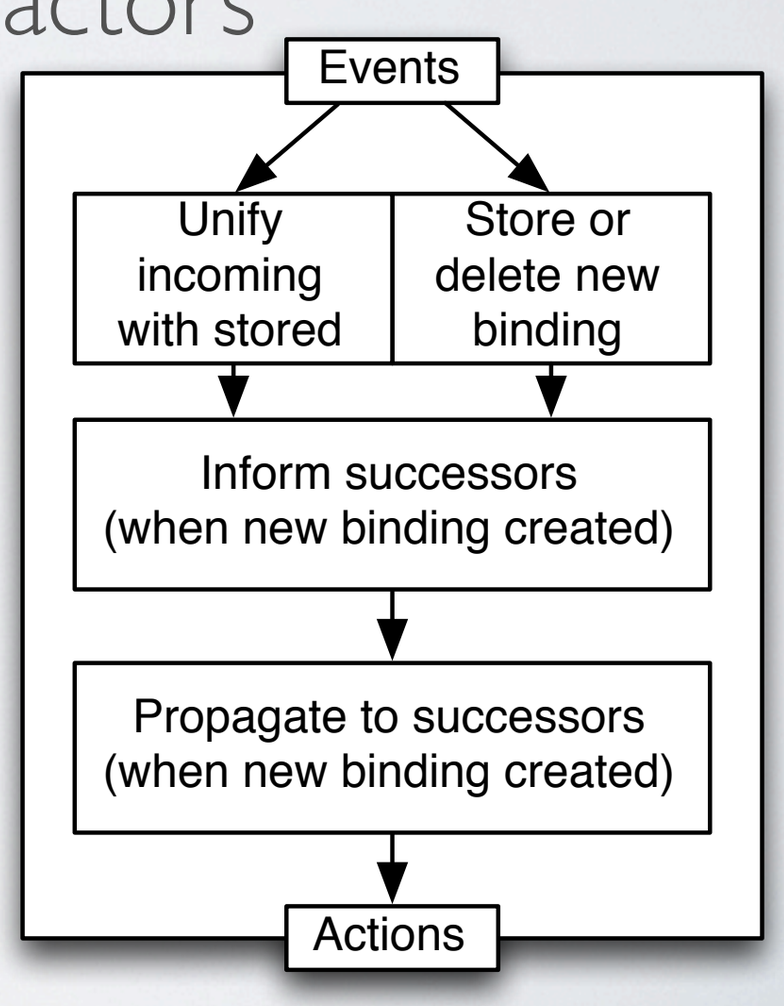
- Among fastest sequential algorithms
- Transforms rules into DAG
- Caches partial matches
- Maps naturally onto actors
  - No shared state
  - Communication explicit
  - But with specific requirements from the application domain



MESSAGES AND ACTIONS

- Only two messages must be understood:
  - **Assert** a new fact
  - **Retract** an old fact





MEMORY MANAGEMENT / EXPIRATION

- Lifetime of facts implicit in the rules
  - If (< (abs (- ?t1 ?t2)) MAX_DELAY)
  - And there has been no candidate for ?t2 for MAX_DELAY
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- Keeping track of time at your predecessors
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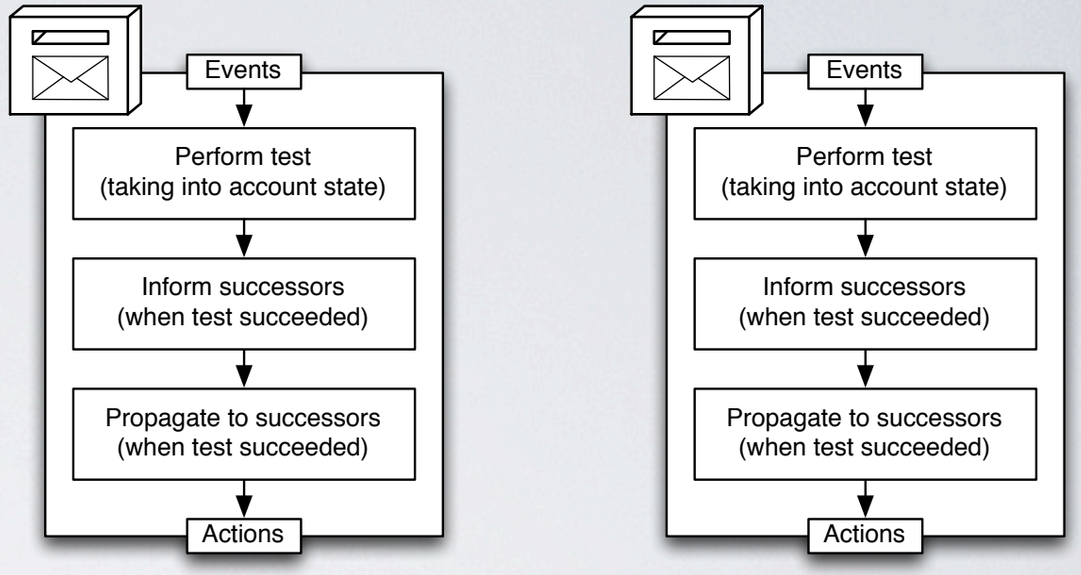
- Discarding expired facts requires no syncing
- But this also means our actors only respond to a single message...

DEADLINES

- Guaranteed low latency
- Semantics for missing a deadline
  - Dropping events

DEADLINES

- Guaranteed low latency



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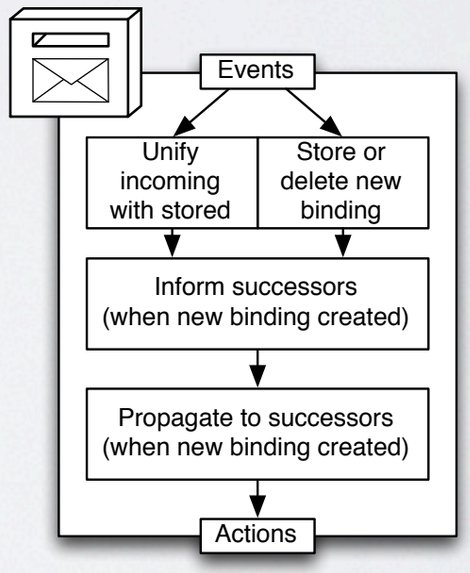
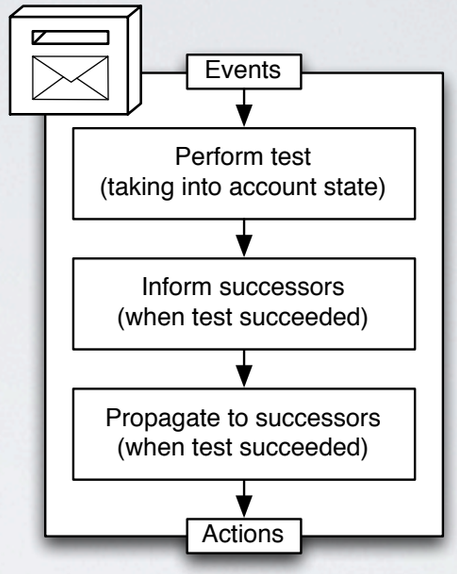
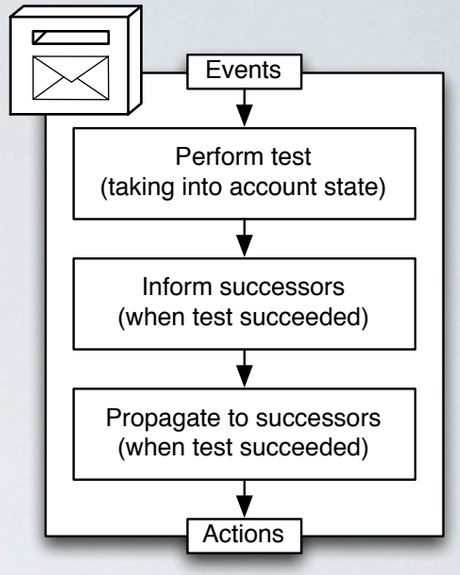


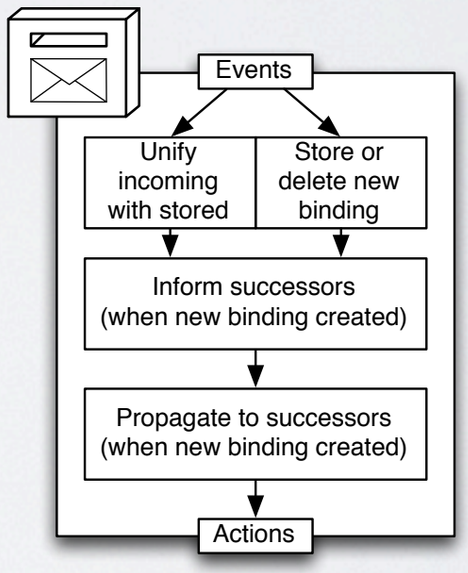
MEETING DEADLINES

Limiting the time spent in

- **Turns** of an actor algorithmically







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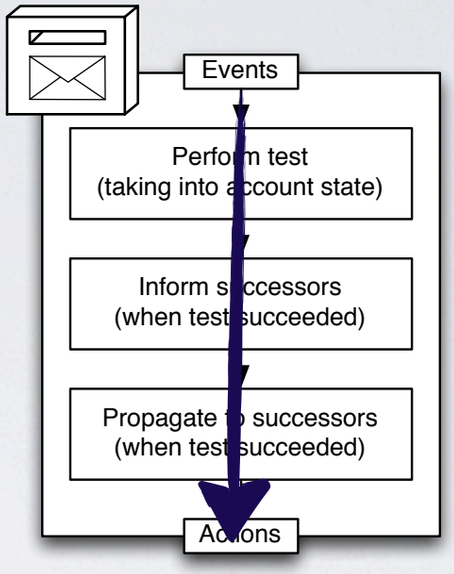

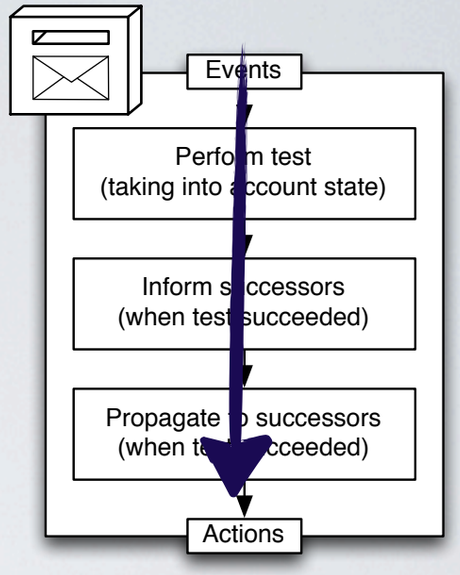

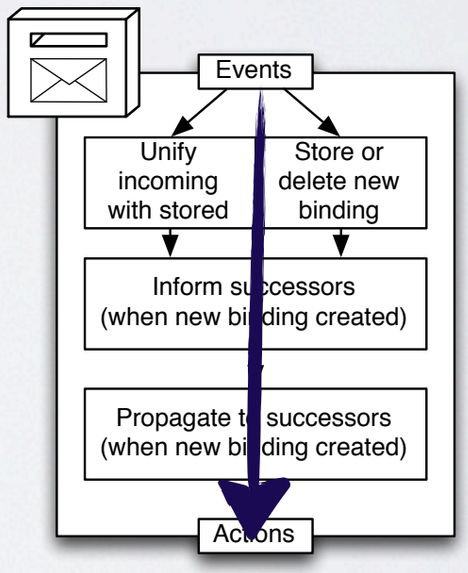

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Limiting the time spent in

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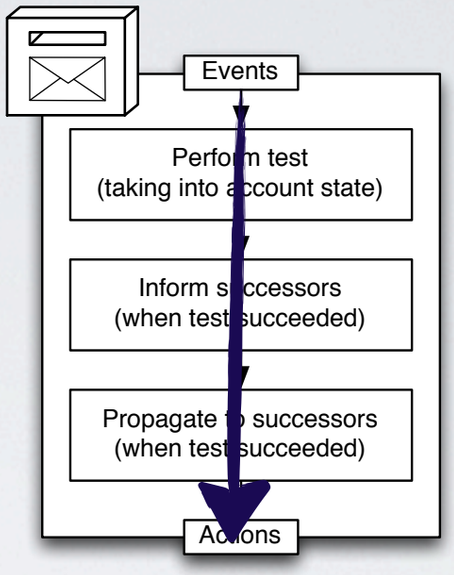
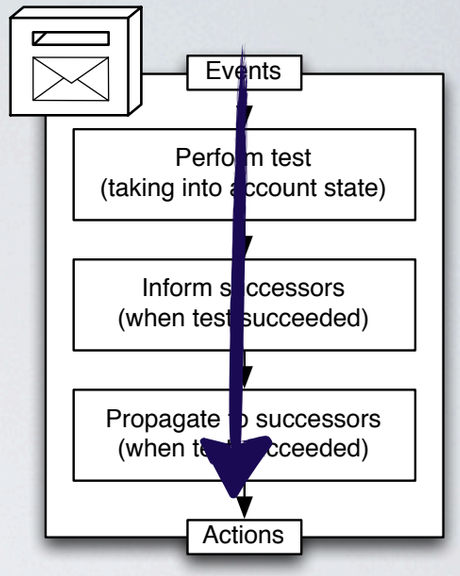
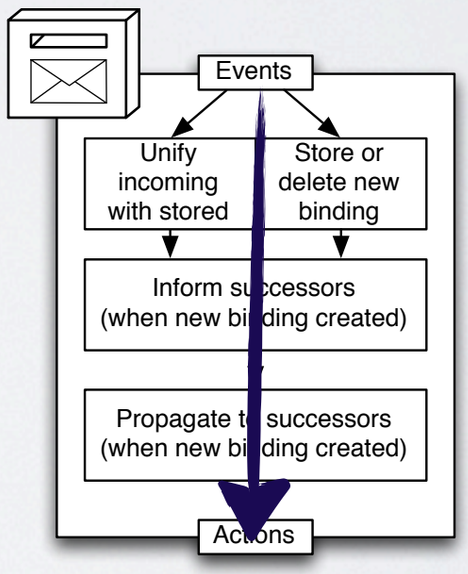
- **Dequeues** and **enqueues** through use of nonblocking inboxes







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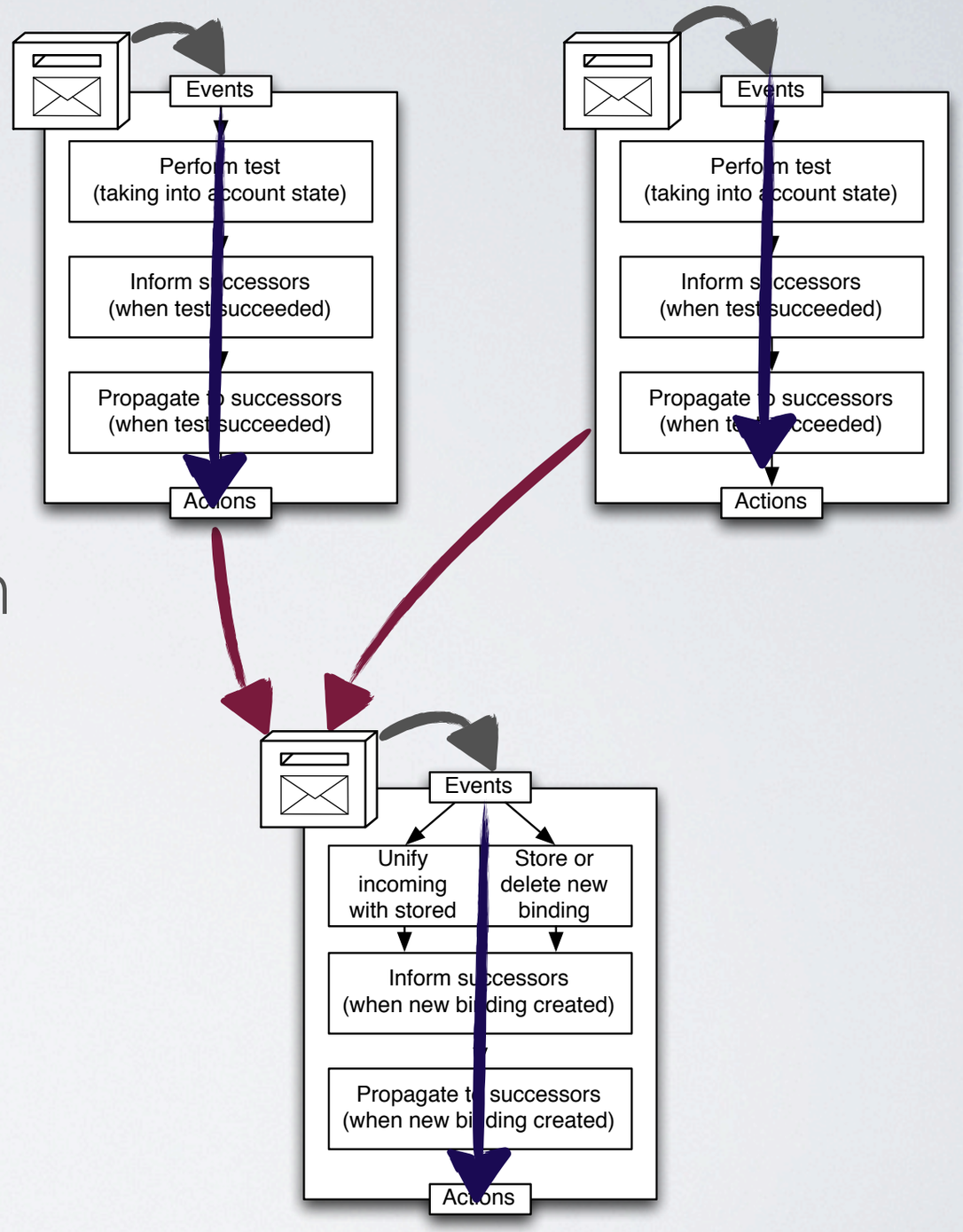
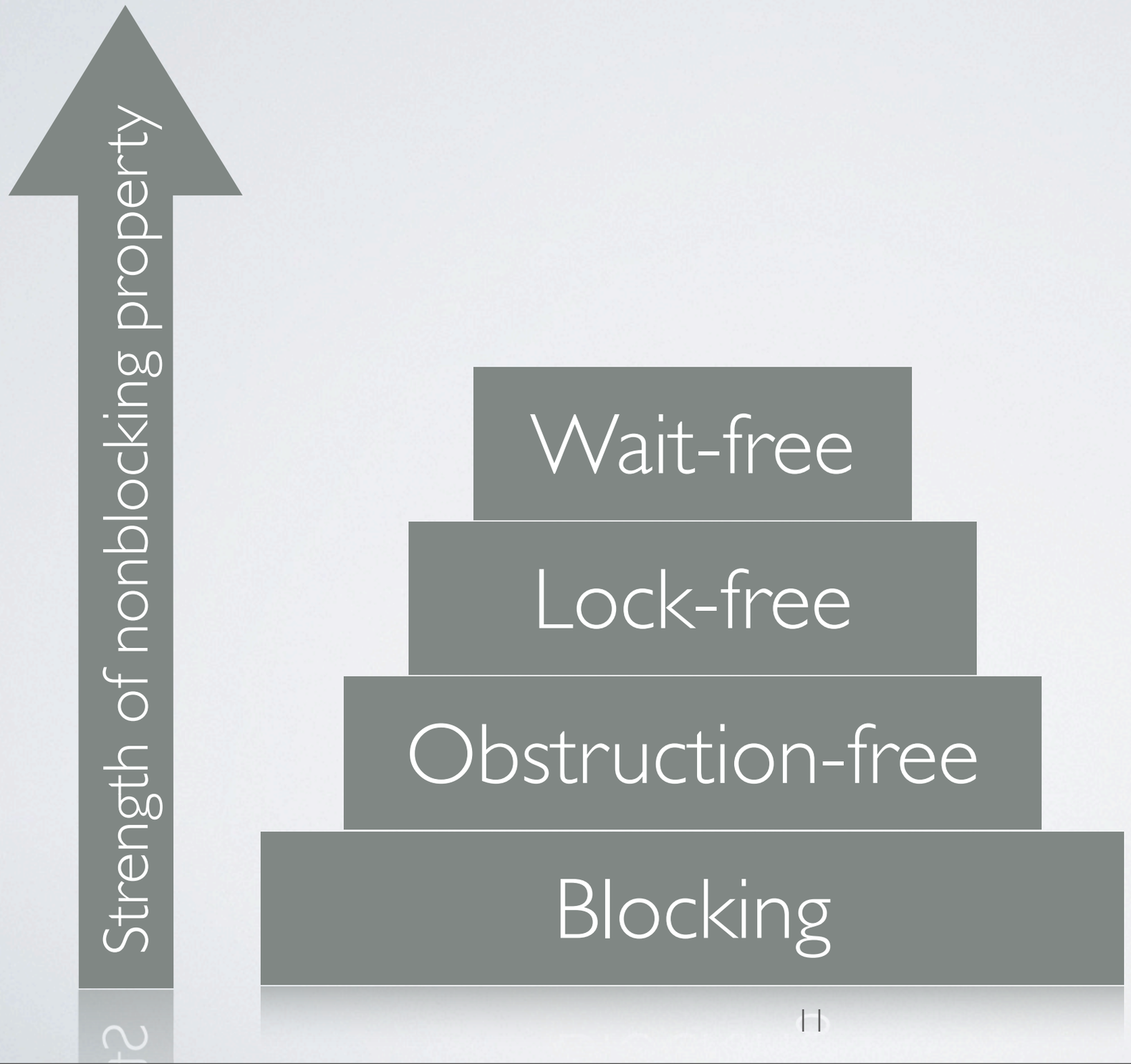


NONBLOCKING DATA STRUCTURES



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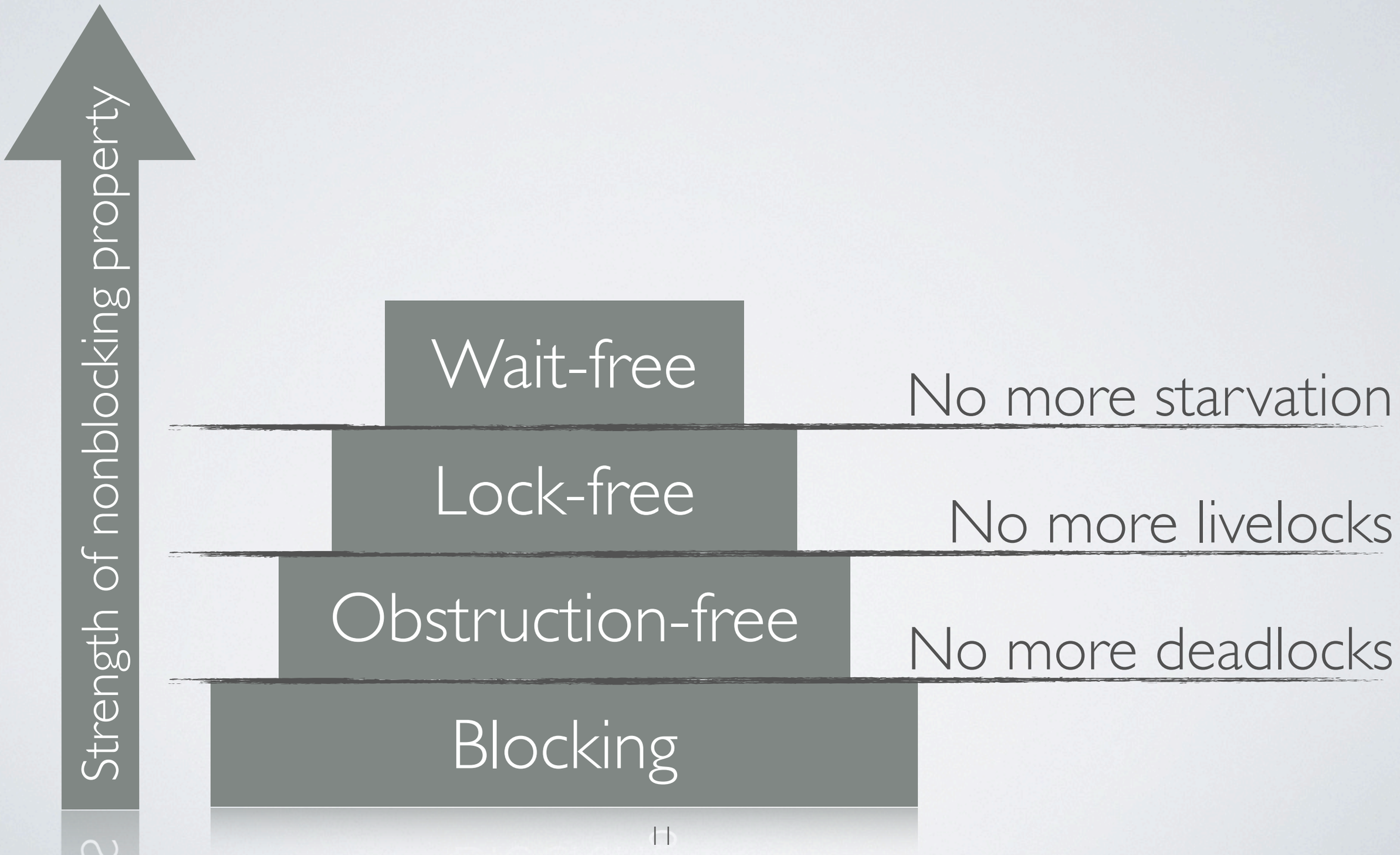

MEETING DEADLINES

Limiting the time spent in

- **Turns** of an actor algorithmically
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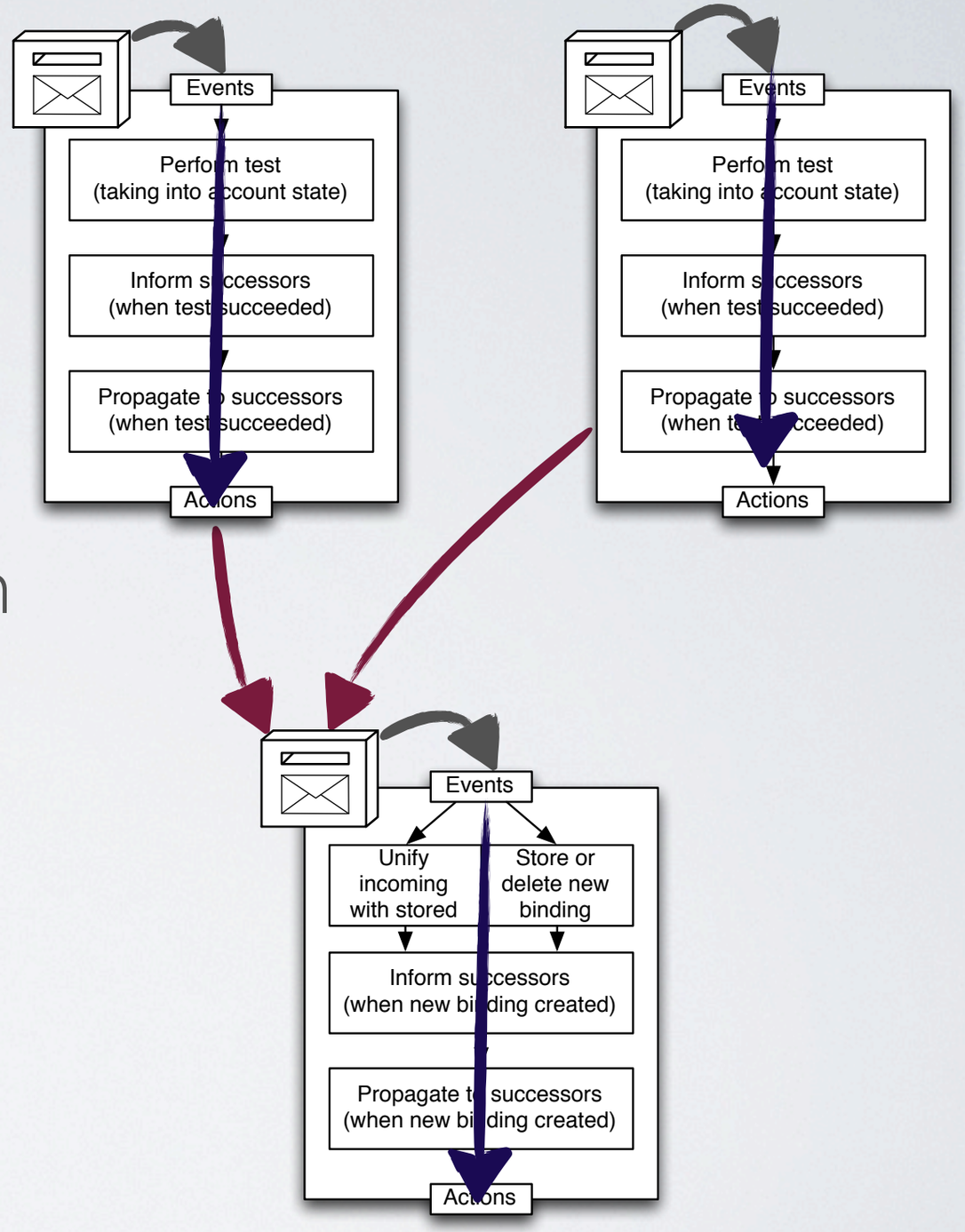
- **Loops** over the entire graph by limiting the DSL's expressiveness



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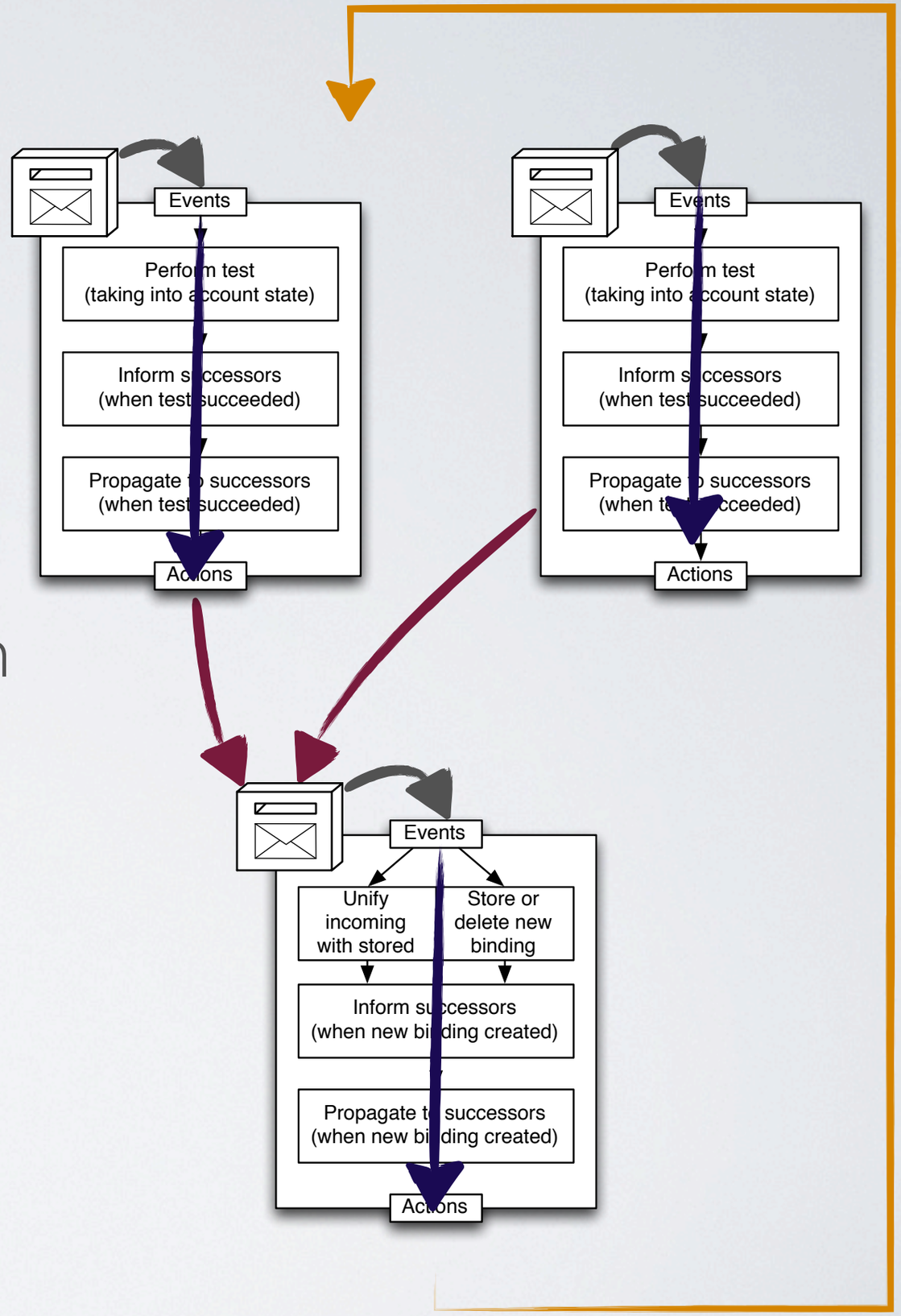
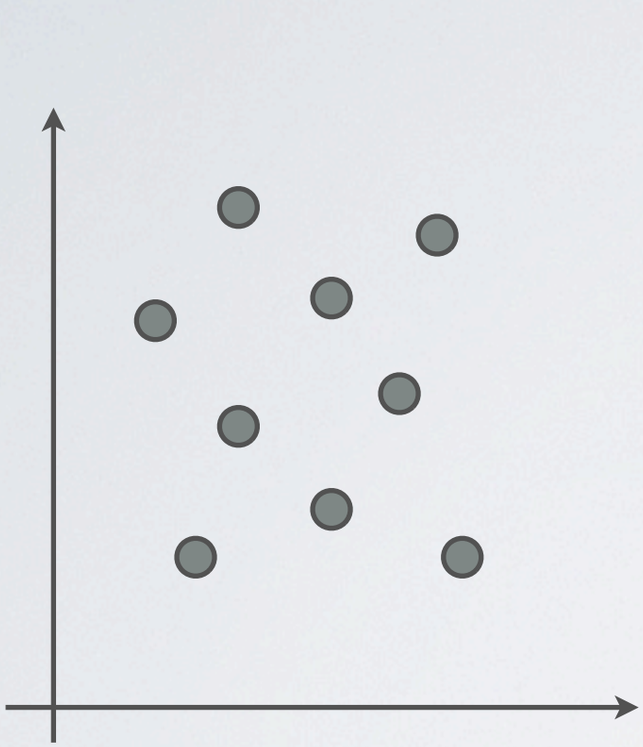
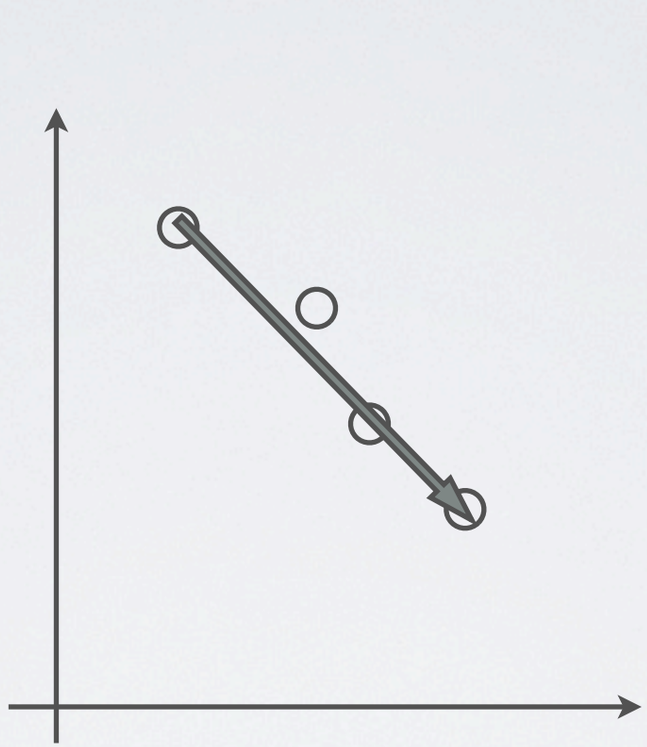


TIERING



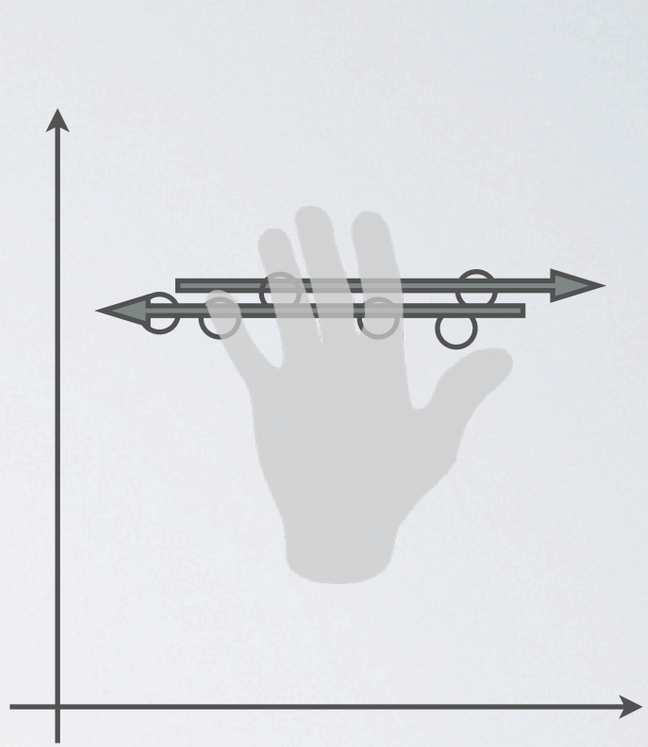
Point

Tier n



Move

Tier n + 1

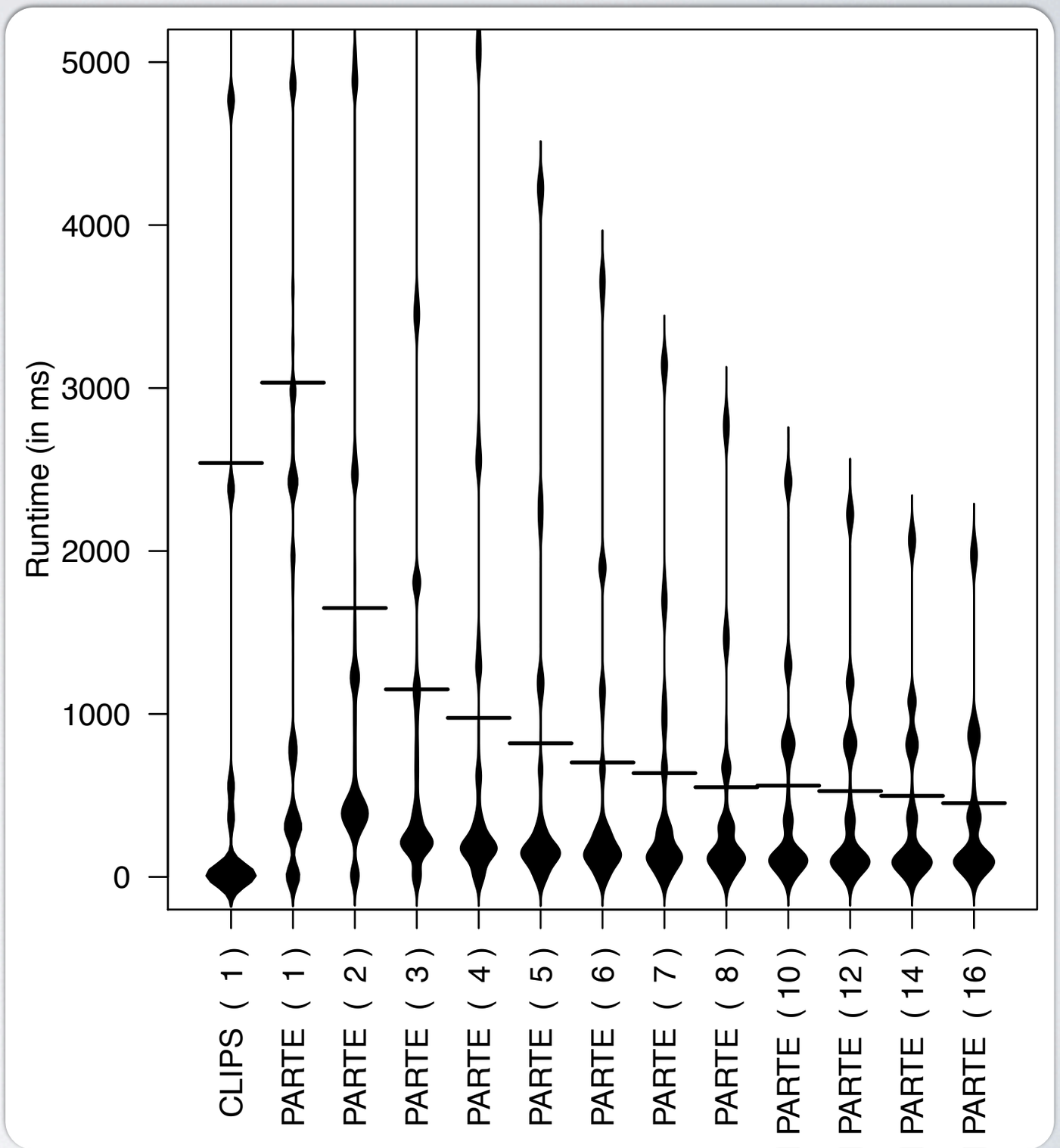


Wave

Tier n + 2

EXECUTION PERFORMANCE

Performance compared to state of the art sequential implementations



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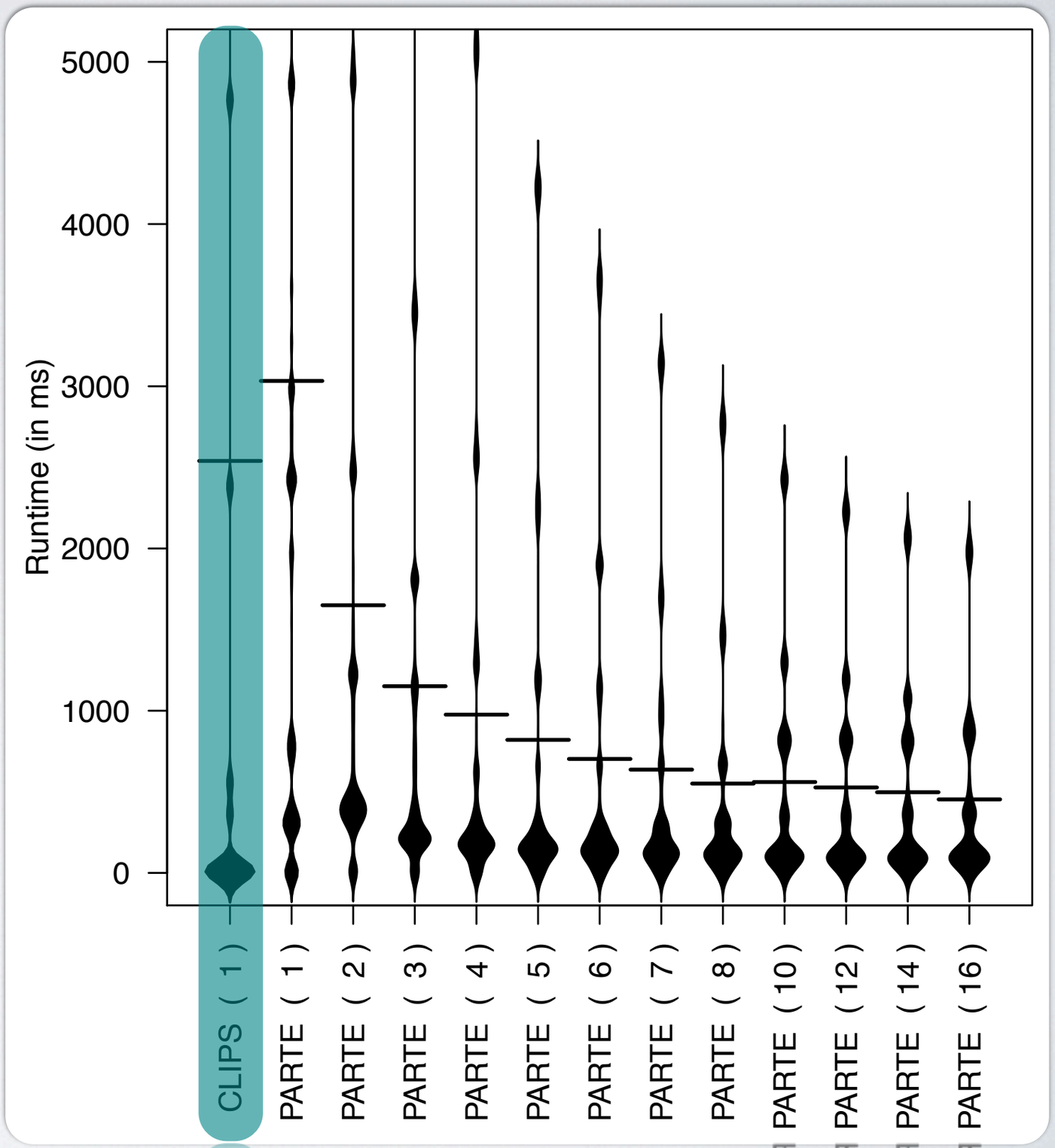

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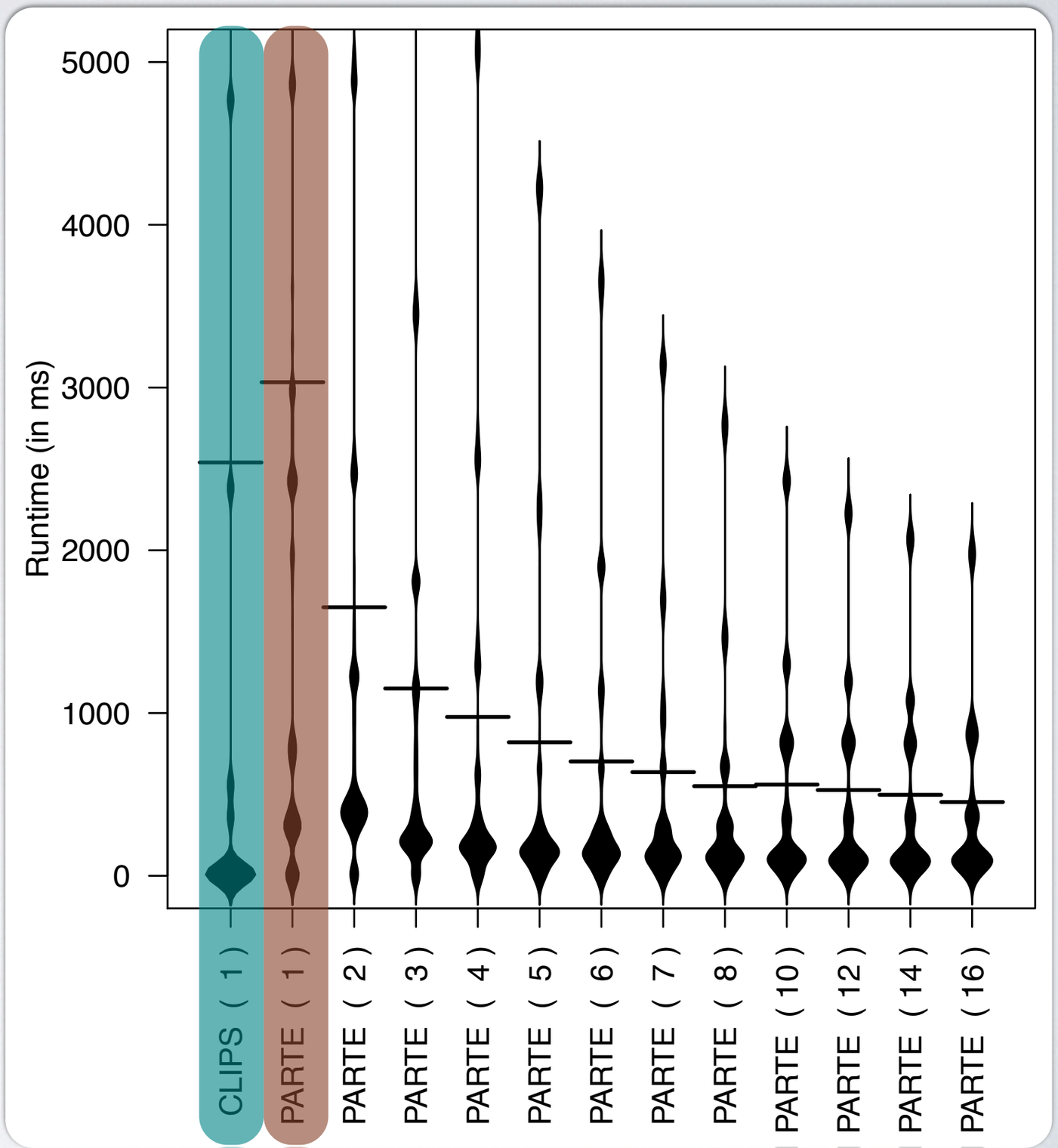

EXECUTION PERFORMANCE

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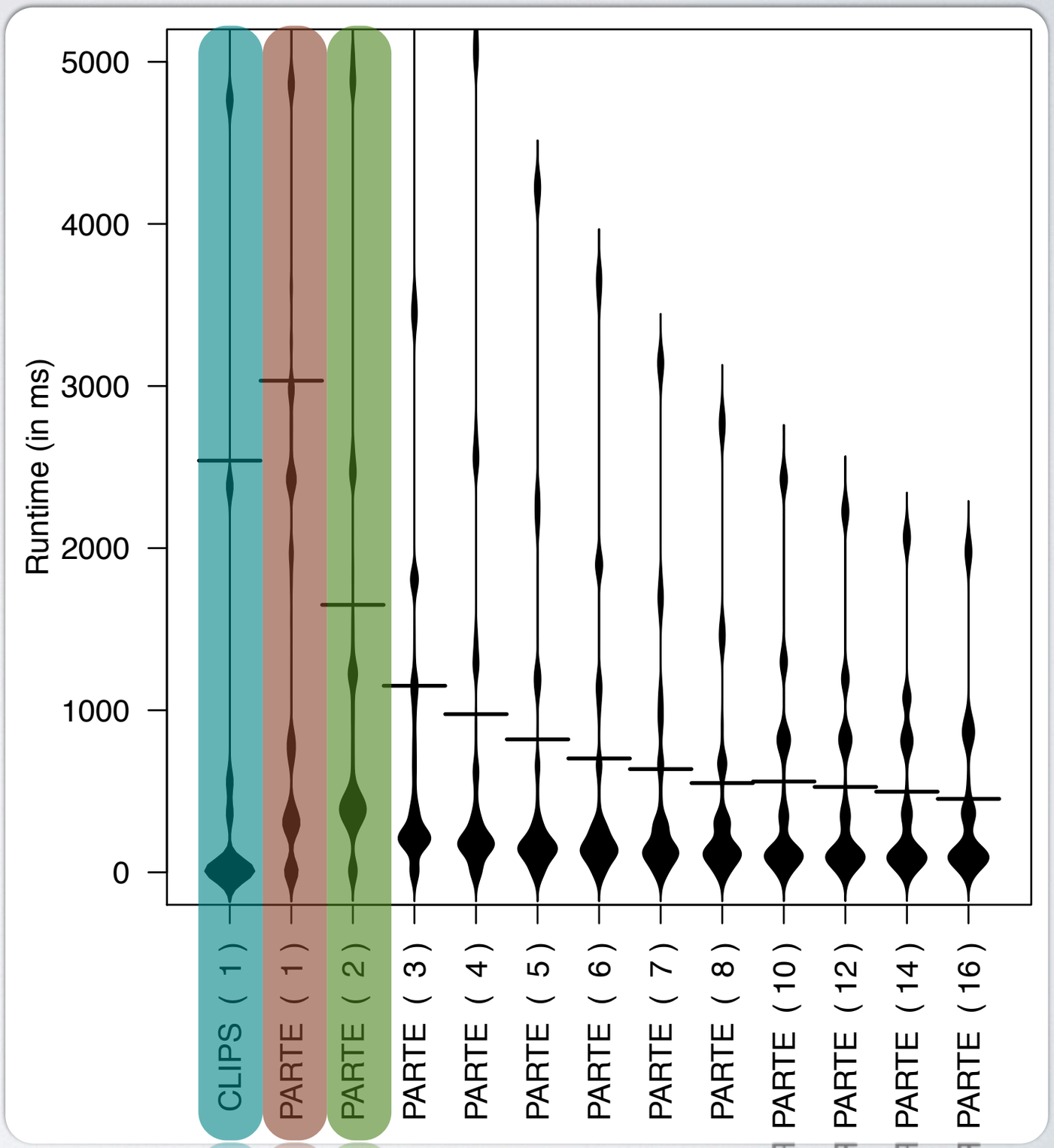

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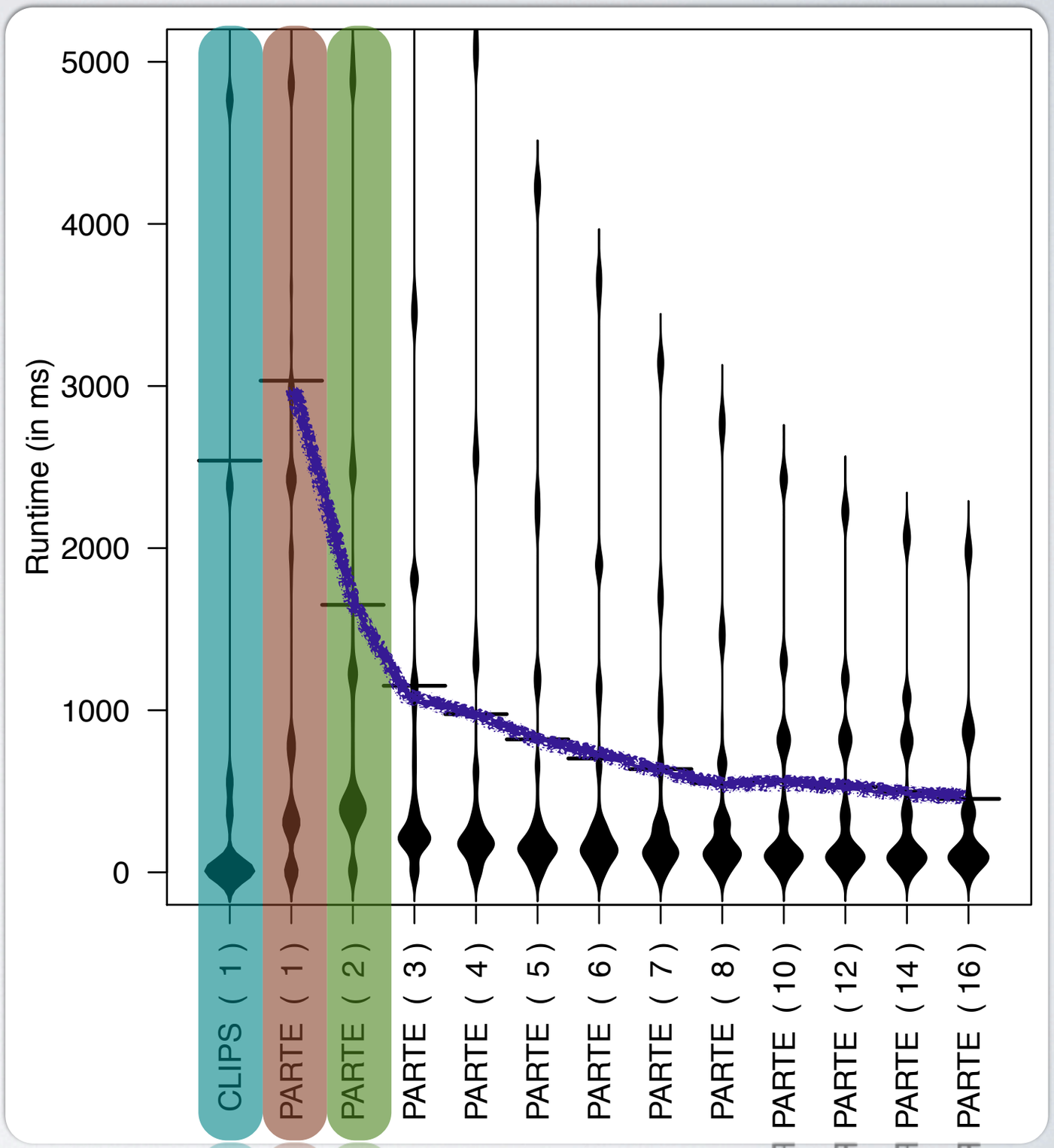
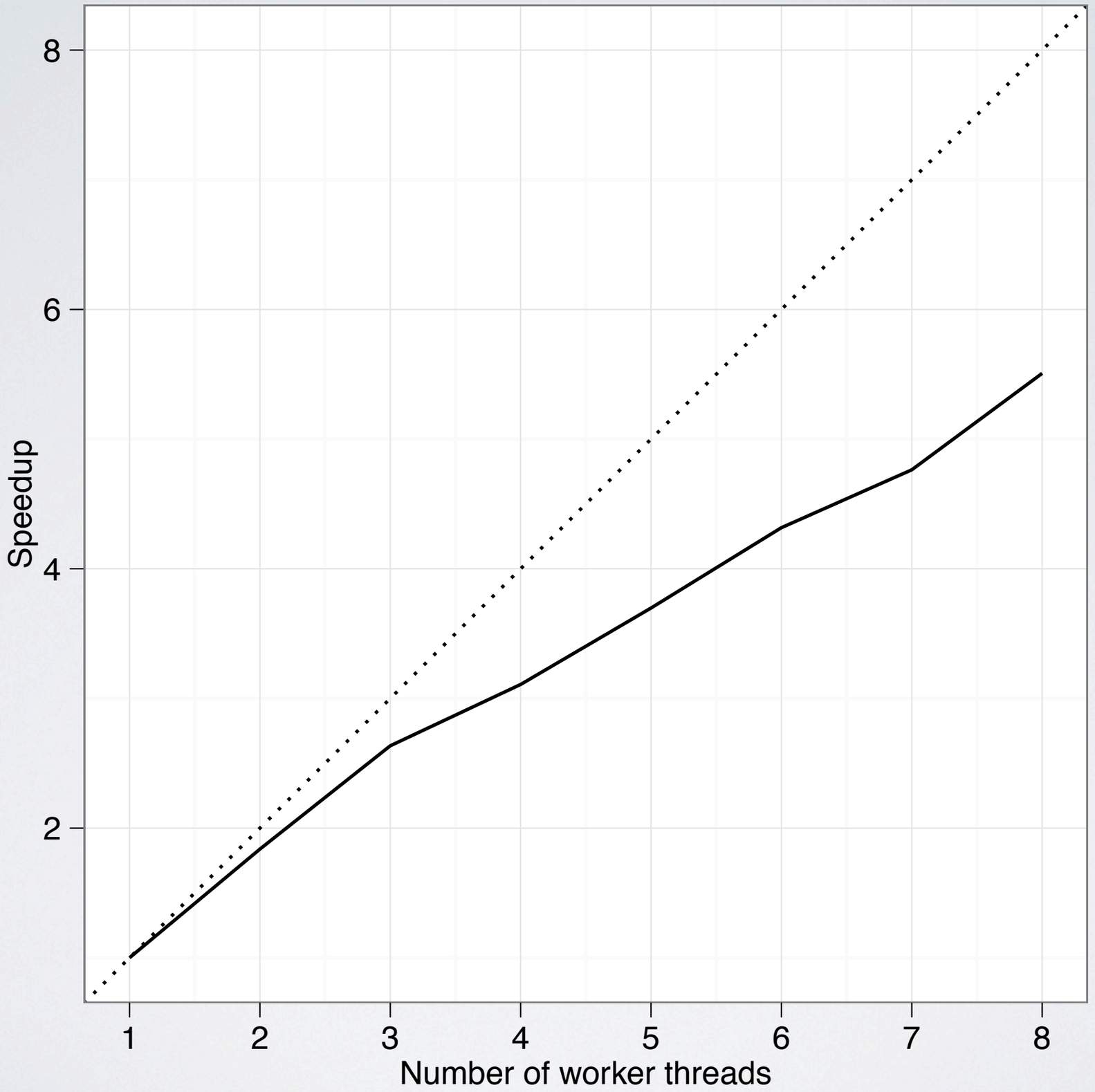


SPEEDUP (ON AN 8-CORE MACHINE)

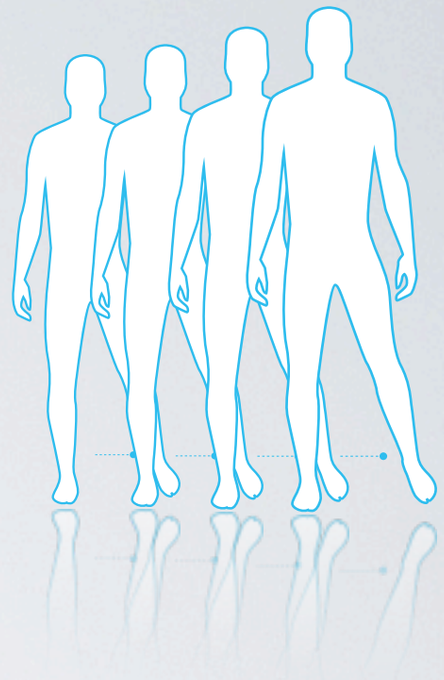


RELATED WORK

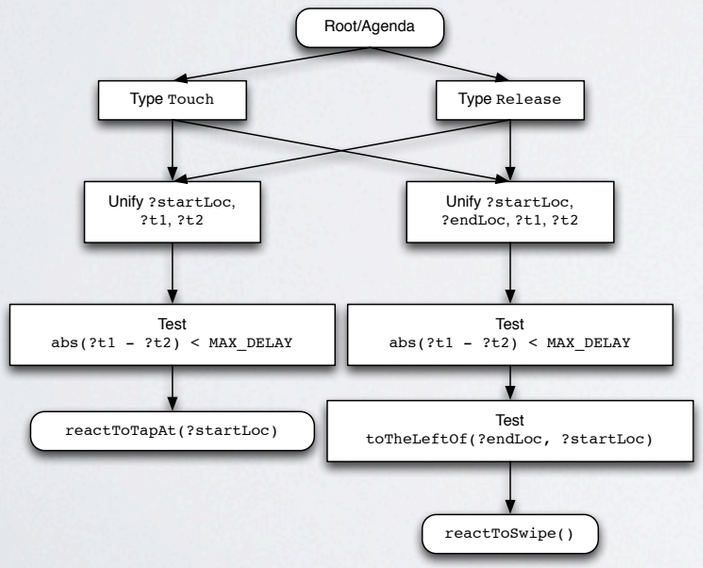
- **Parallel Production System**: K. Oflazer - 1985 - More state-saving
- **Parallel Rete**: Gupta et al. - 1986 - Quite fine-grained, but hardware-based scheduler
- **Treat**: D.P. Miranker - 1987 - Designed for specialized parallel hardware, less state-saving
- **PRAIS**: Goldstein et al. - 1991 - Blackboard, real-time guarantees
- **HOPES**: Dai et al. - 1992 - Blackboard, hierarchically organized
- **Lana**: Aref et al. - 1998 - Optimistic synchronization

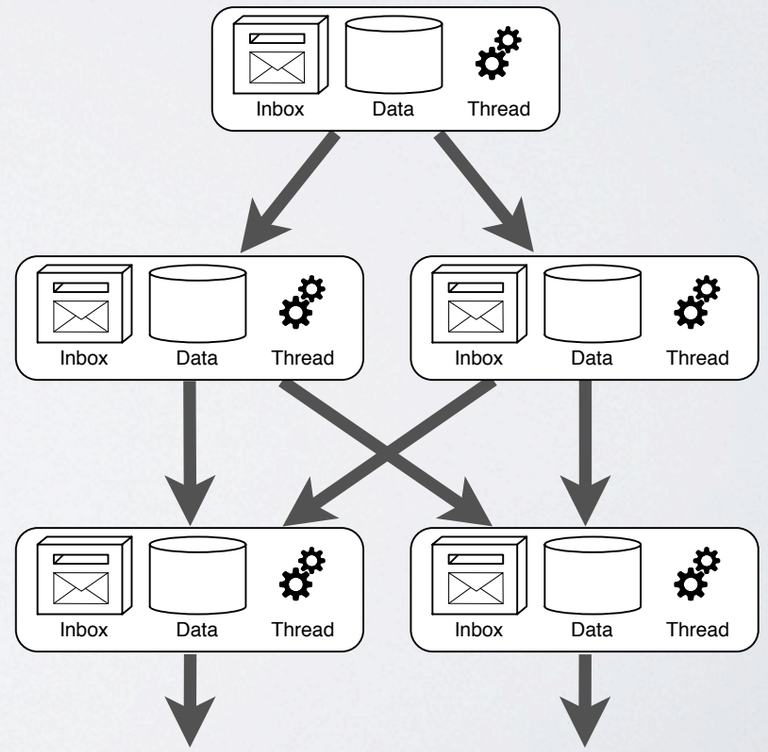
SUMMARY

- Problem:
  - Need for CED with guaranteed low latency



- Solution:
  - Actors with soft real-time guarantees





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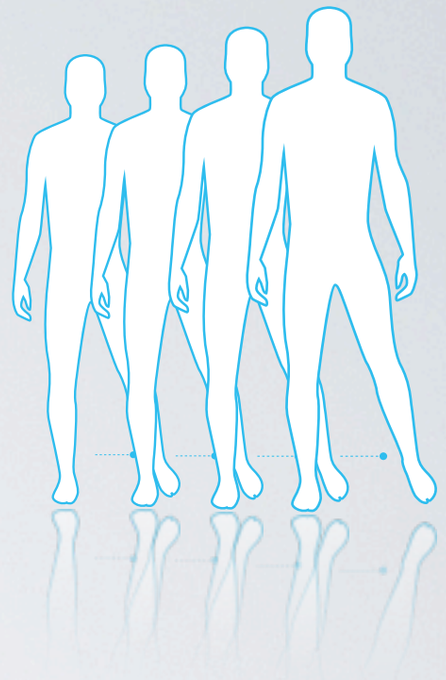

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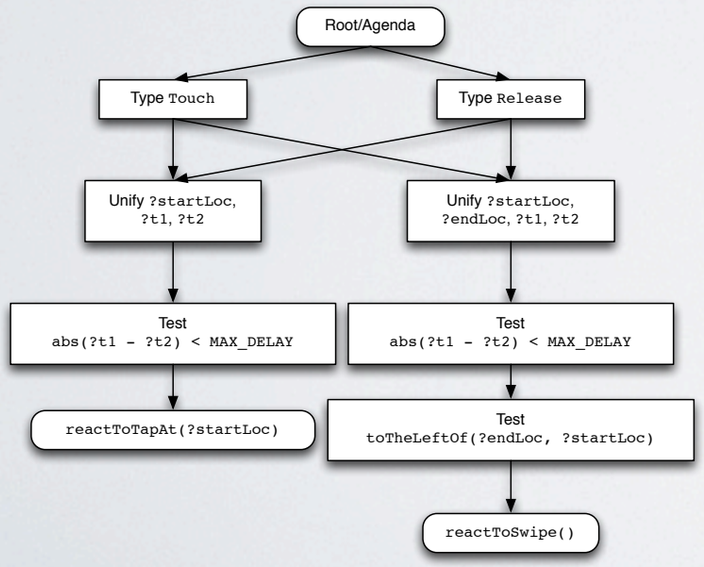

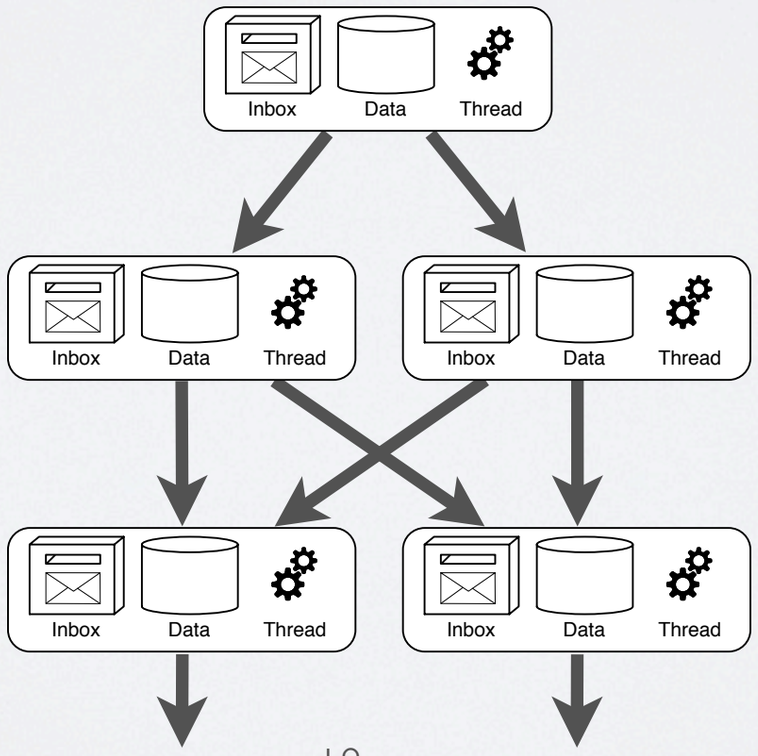

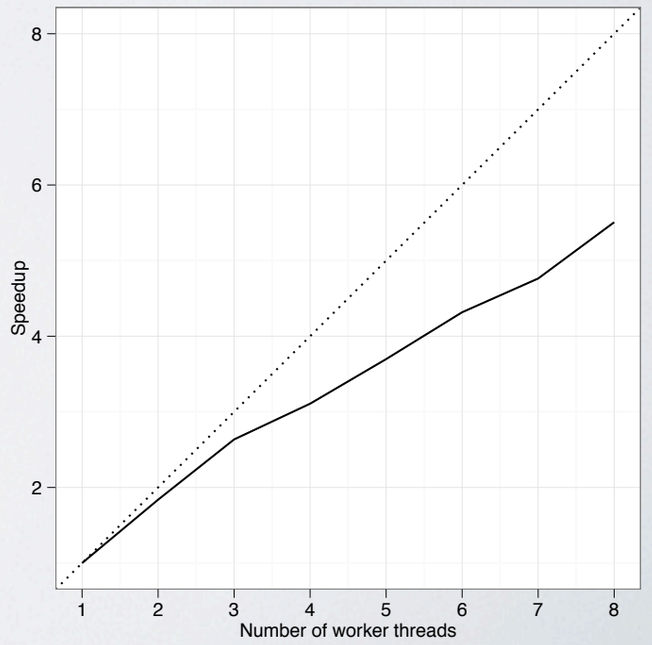

PARALLEL GESTURE RECOGNITION WITH SOFT REAL-TIME GUARANTEES

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