Transactional Actors
Communication in Transactions

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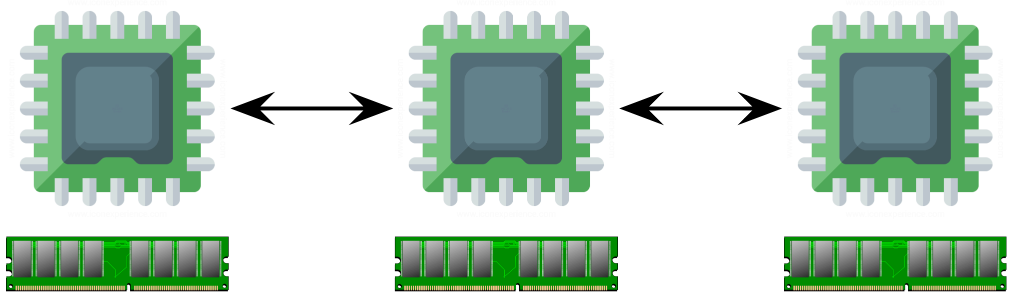
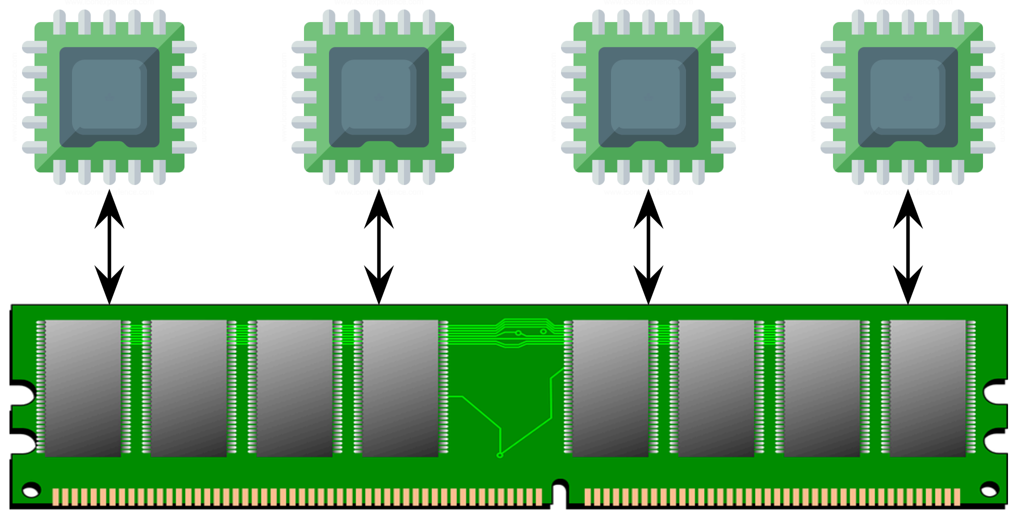
There are many concurrency models

active objects Nested Data Parallelism
Software Transactional Memory
futures dataflow actors locks threads MPI OpenMP Fork/Join MapReduce
transactional events worlds
Concurrent Revisions promises
Communicating Sequential Processes speculative parallelism

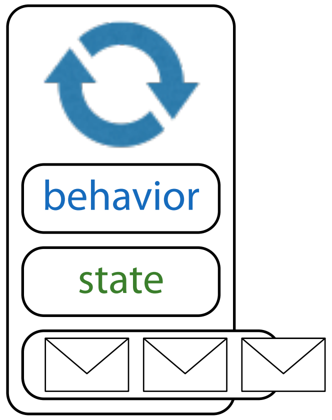
Two categories:

Message passing ↔ Shared memory





Actors

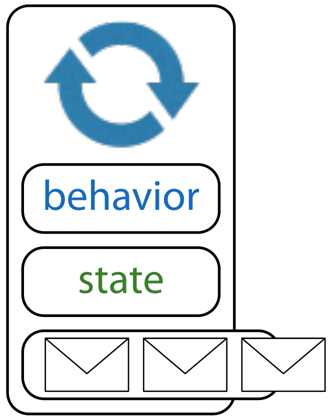


```
(def airline-behavior
  (behavior [flights]
    [orig dest n]
    (let [flight   (search-flight flights orig dest)
          flight'  (reserve flight n)
          flights' (replace flights flight flight')]
      (become airline-behavior flights'))))

(def air-canada
  (spawn airline-behavior
    {"AC854" {:orig "YVR" :dest "LHR" :seats 211}
     "AC855" {:orig "LHR" :dest "YVR" :seats 211}}))

(send air-canada "LHR" "YVR" 2)
```

Actors



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  (behavior [flights]
    [orig dest n]
    (let [flight   (search-flight flights orig dest)
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          flights' (replace flights flight flight')]
      (become airline-behavior flights'))))
```

turn

```
(def air-canada
  (spawn airline-behavior
    {"AC854" {:orig "YVR" :dest "LHR" :seats 211}
     "AC855" {:orig "LHR" :dest "YVR" :seats 211}}))

(send air-canada "LHR" "YVR" 2)
```

no low-level data races

no deadlocks

Software Transactional Memory

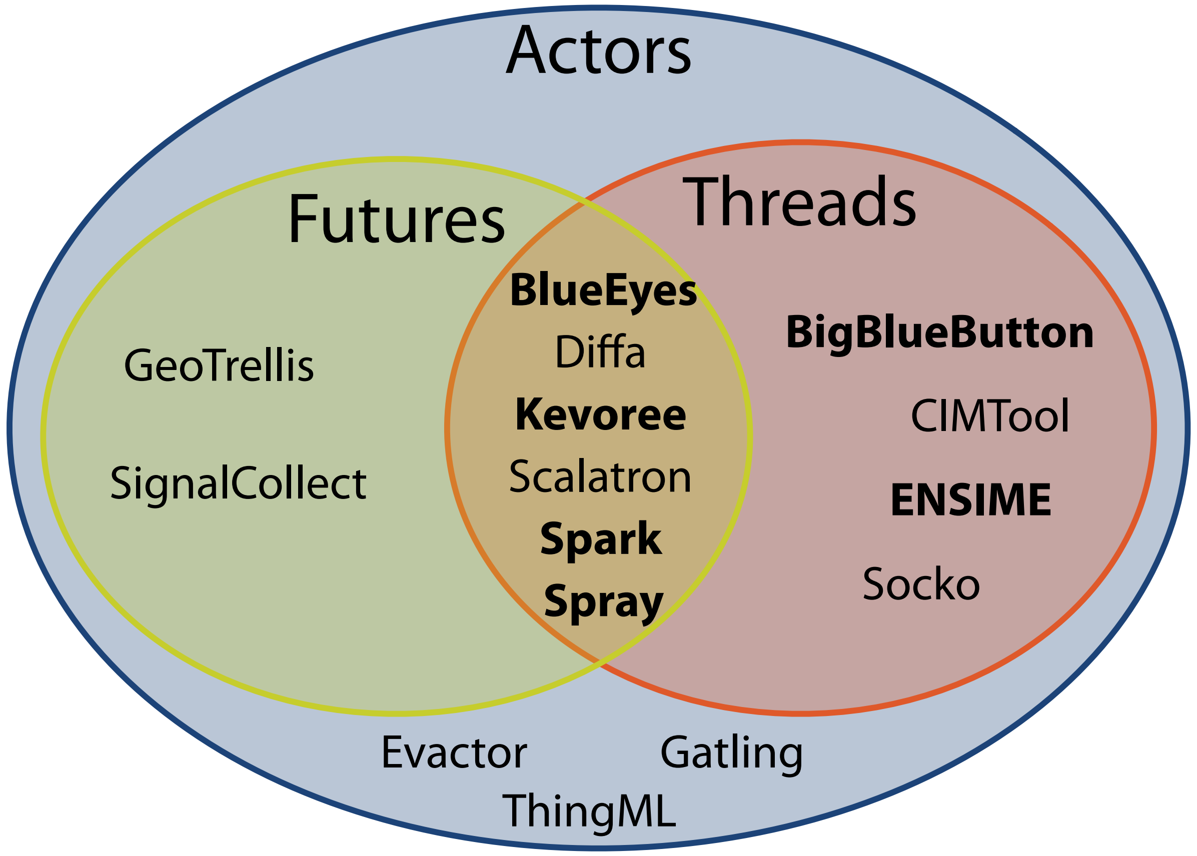
```
(def flights
  {"AC854" {:orig "YVR" :dest "LHR" :seats (ref 211)}
   "AC855" {:orig "LHR" :dest "YVR" :seats (ref 211)}…})

(dosync
  (let [outbound (get (get flights "AC854") :seats)
        return   (get (get flights "AC855") :seats)]
    (if (and (>= @outbound 2) (>= @return 2))
      (do (ref-set outbound (- @outbound 2))
          (ref-set return   (- @return   2)))
      (println "Not enough seats available"))))
```

trans-
action

serializability

Actors often share memory



Study of 15 Scala programs that use actors:

- 12/15 (80%) combine with another model
- 6/15 (40%) say they circumvent it where it is "not a good fit"

data races and deadlocks possible

Tasharofi, Dinges, and Johnson (2013). *Why Do Scala Developers Mix the Actor Model with Other Concurrency Models?* (ECOOP'13)

Vacation benchmark

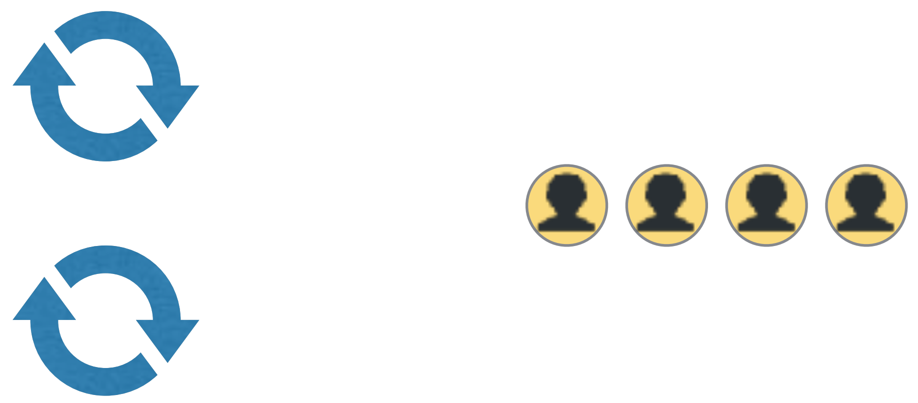
```
(def flights   [(ref {:id "AC855"
                      :price 499
                      :orig "London" :dest "Vancouver" …})
                …])
(def rooms     [(ref {:id 101 …}) …])
(def cars      [(ref {:id "ABC123" …}) …])

(def customers [(ref {:orig "London" :dest "Vancouver"
                      :start "2017-10-22" :end "2017-10-27"
                      :password nil})
                …])
```

```
(defn process-customer [c]
  (dosync
    (reserve-flight (:orig @c) (:dest @c) (:start @c))
    (reserve-flight (:dest @c) (:orig @c) (:end @c))
    (reserve-room   (:dest @c) (:start @c) (:end @c))
    (reserve-car    (:dest @c) (:start @c) (:end @c))
    (ref-set c (assoc @c :password (generate-password)))))
```

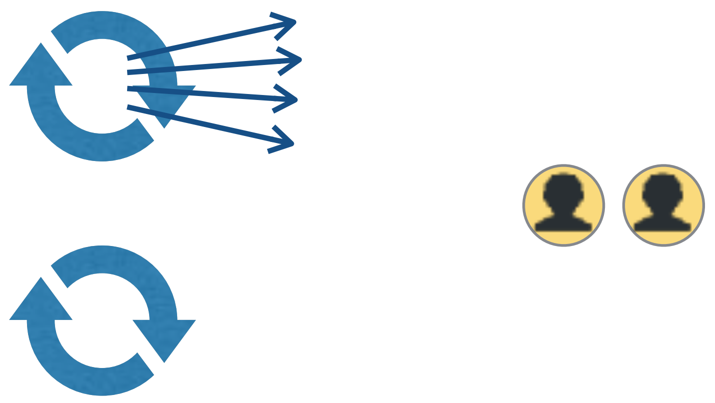
Based on: Minh, Chung, Kozyrakis, Olukotun (2008). *STAMP: Stanford Transactional Applications for Multi-Processing* (IISWC'08)

Customers are processed in parallel



```
(defn process-customer [c]
  (dosync
    (reserve-flight (:orig @c) (:dest @c) (:start @c))
    (reserve-flight (:dest @c) (:orig @c) (:end @c))
    (reserve-room   (:dest @c) (:start @c) (:end @c))
    (reserve-car    (:dest @c) (:start @c) (:end @c))
    (ref-set c (assoc @c :password (generate-password)))))
```

But more fine-grained parallelization is possible



```
(defn process-customer [c]
  (dosync
    (send (rand workers) :flight (:orig @c) …)
    (send (rand workers) :flight (:dest @c) …)
    (send (rand workers) :room   (:dest @c) …)
    (send (rand workers) :car    (:dest @c) …)
    (ref-set c (assoc @c :password (generate-password)))))
```

serializability broken

Observations:

Actors often share memory
⇒ **races & deadlocks possible**

Transactions contain subtasks that may be parallelized
⇒ **serializability broken**

Actors + Transactions = Problems

Solution: Transactional Actors

	Transaction in...	Actor in ...
...in transaction	**(dosync** (dosync (ref v) (deref r) (ref-set r v))) ✓	**(dosync** (behavior [] [] …) (spawn beh state) (become beh state) (send actor msg)) ?
...in actor	**(behavior [] []** (dosync (ref v) (deref r) (ref-set r v))) ?	**(behavior [] []** (behavior [] [] …) (spawn beh state) (become beh state) (send actor msg)) ✓

Transactional memory in actors

Similar to thread-based systems

```
(behavior [] [c]
  (process-customer c))
```

$\longrightarrow$

```
(defn process-customer [c]
 (dosync
   (reserve-flight (:orig @c) (:dest @c) (:start
   (reserve-flight (:dest @c) (:orig @c) (:end @c
   (reserve-room   (:dest @c) (:start @c) (:end @
   (reserve-car    (:dest @c) (:start @c) (:end @
   (ref-set c (assoc @c :password (generate-passw
```

Actors in a transaction

Difficulty: side effects in transaction

```
(dosync

  (def airline-beh
    (behavior [flights]
      …))


  (spawn airline-beh @flights)
  (become airline-beh @c)

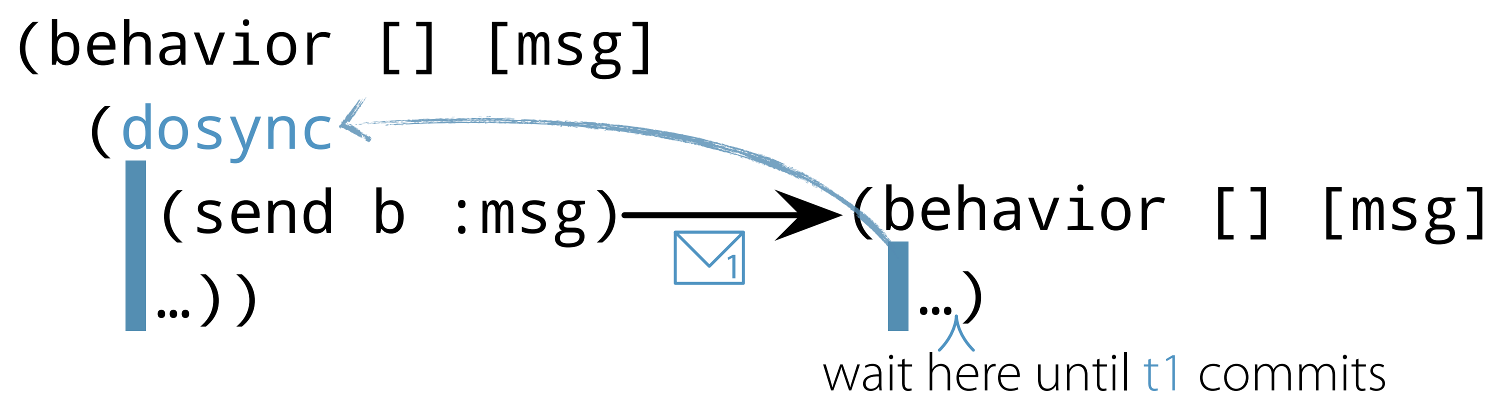

  (send :process-customer @c))
```

separate from transaction, no side-effect ✓

delay side effect until commit (pessimistic) ↷

sent immediately, but **rolled back** on abort (optimistic) ↶

Sending a message in a transaction



```
(behavior [] [msg]
  (dosync
   (send b :msg)
   …))
```

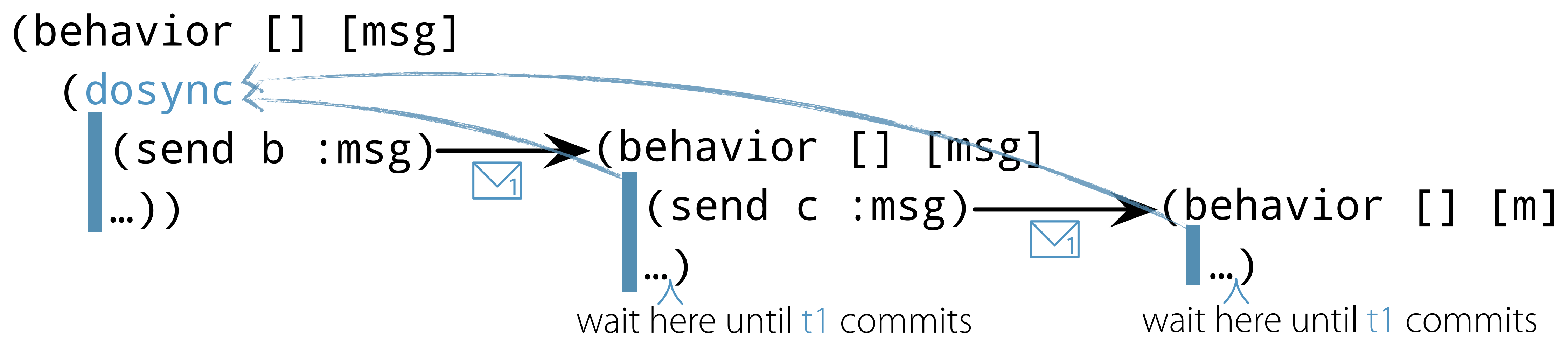
```
(behavior [] [msg]
 …)
```

Message **depends** on the transaction

Receiving turn is **tentative**:

- Side effects (`spawn`, `become`) delayed
- At the end, wait for dependency to commit

Special case: Message in tentative turn



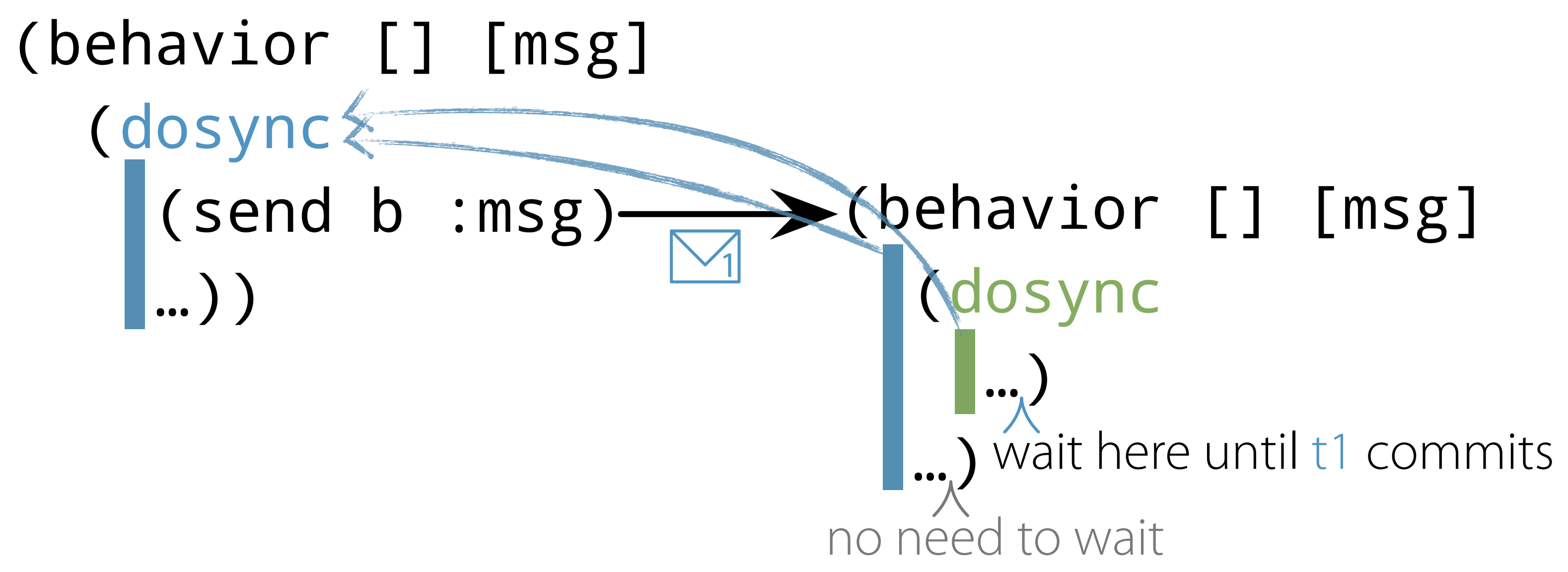
```
(behavior [] [msg]
  (dosync
    (send b :msg)
    …))
```

```
(behavior [] [msg]
  (send c :msg)
  …)
```

```
(behavior [] [m]
  …)
```

Dependency is **forwarded**

Special case: Transaction in tentative turn



```
(behavior [] [msg]
  (dosync
   (send b :msg))
   …))
```

```
(behavior [] [msg]
  (dosync
   …)
  …)
```

Transaction in tentative turn waits before it commits

⇒ serializability maintained

Properties

Serializability

side effects on actors part of transaction

but: other side effects not allowed in tentative turns

Free from deadlocks

dependencies always from new to old

but: transactions cannot cross turns

Free from low-level races

granularity of turns & transactions

Implementation

Fork of Clojure

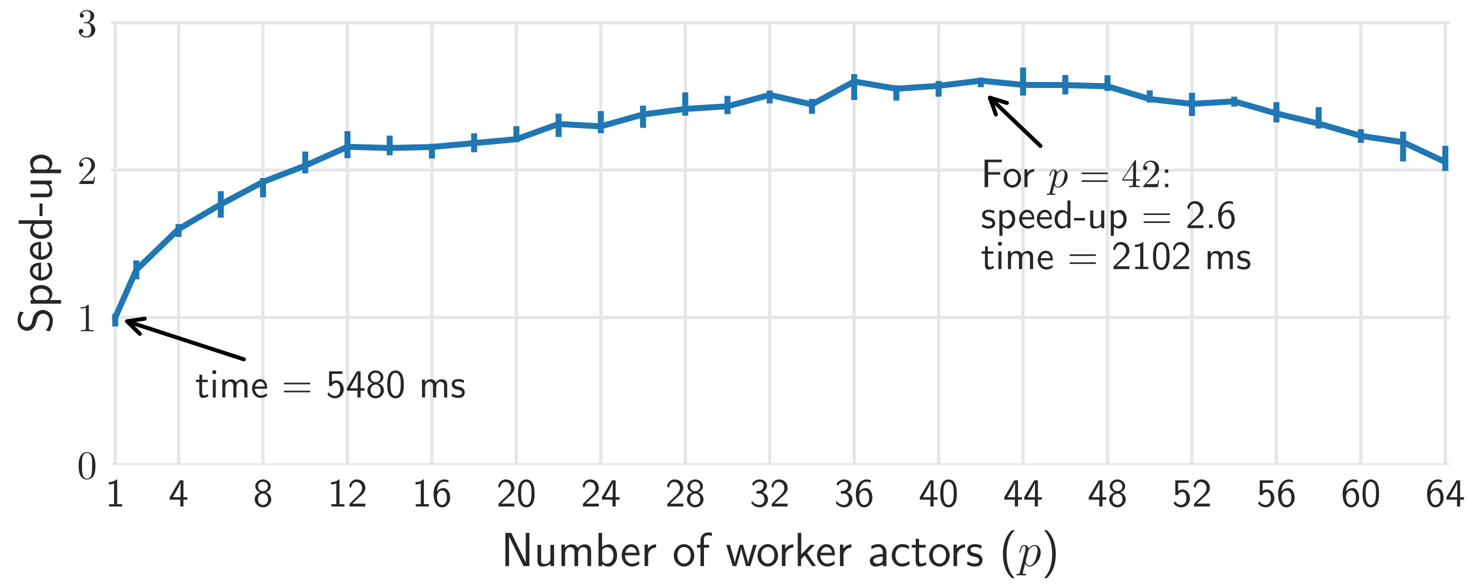
- STM built-in
- Regular actors added
- Transactional Actors as modifications of STM & actors

Details in paper

https://github.com/jswalens/transactional-actors

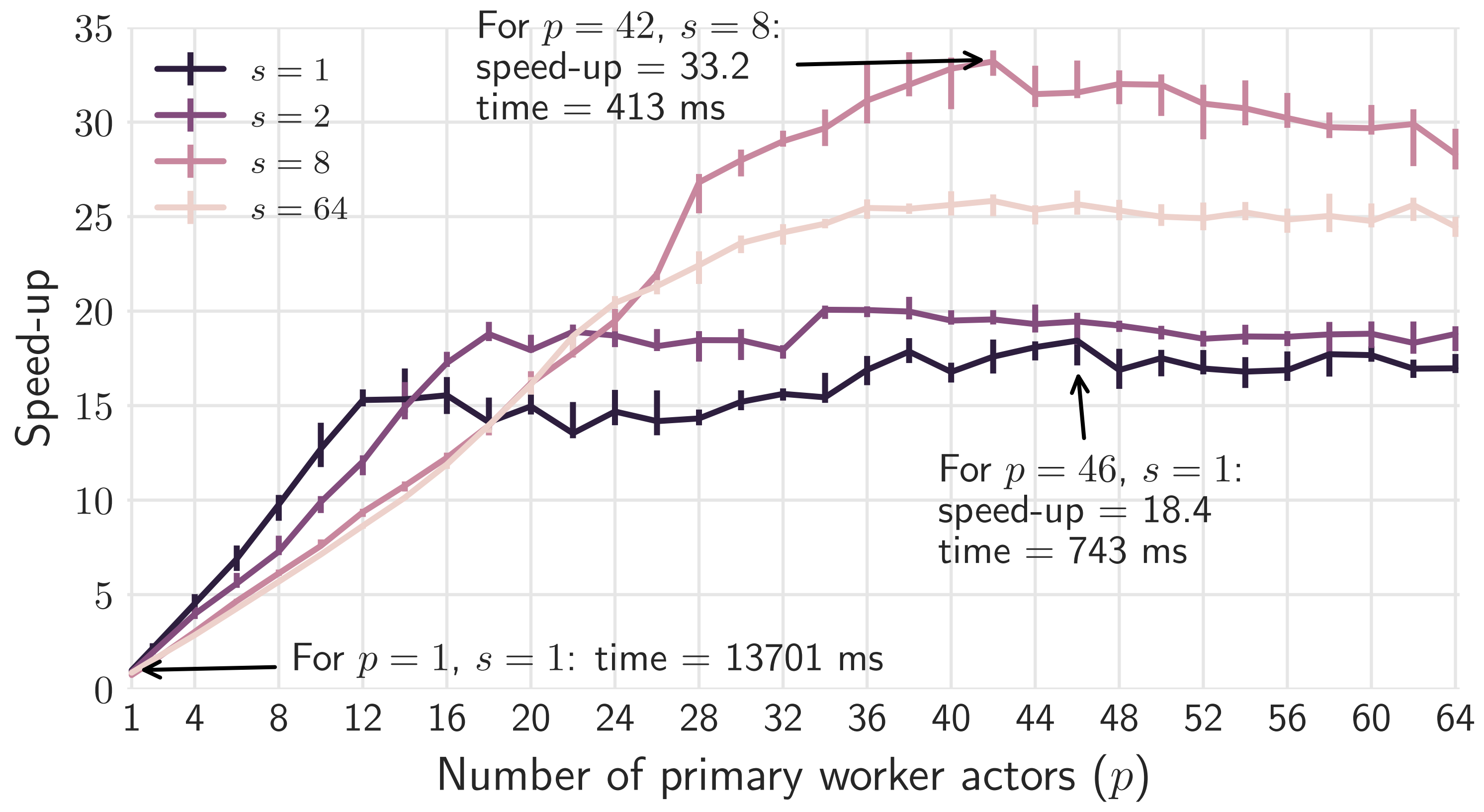
Evaluation: Vacation benchmark

Original



Speed-up limited: 2.6 because of conflicts

Transactional Actors



Better speed-up due to:

- finer-grained parallelism
- fewer/cheaper conflicts

For 1 thread: much slower

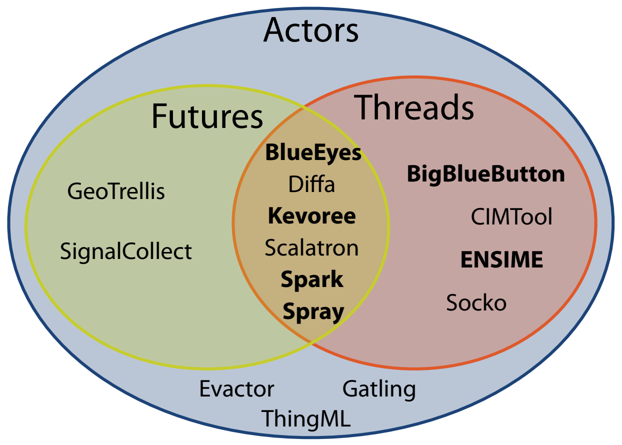
Limitations & Future Work

- Implement optimizations
- Evaluate:
  - **More benchmark applications** (suggestions?)
  - **Comparison with related work** (performance & software quality atttributes)
- Formalize of semantics and properties

Summary

Problem:

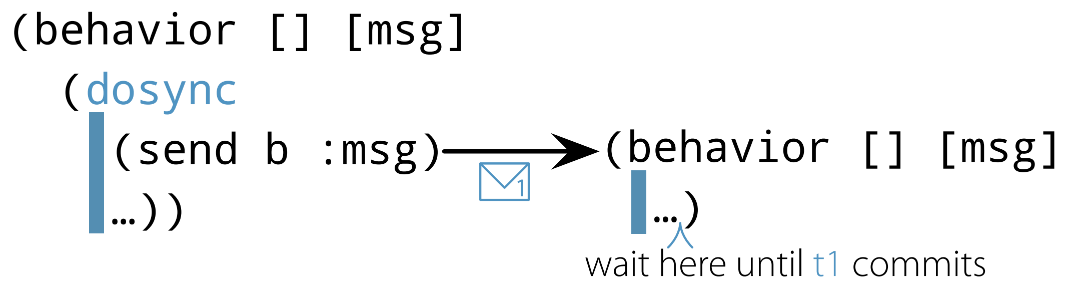
Shared memory & message passing often combined, but breaks properties



Solution:

Transactional Actors

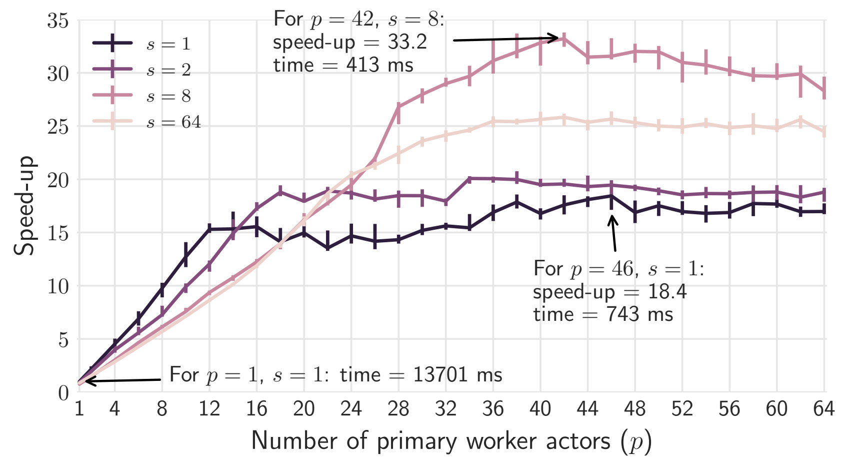
- Messages have a dependency
- Transaction aborts
  ⇒ all its effects are rolled back



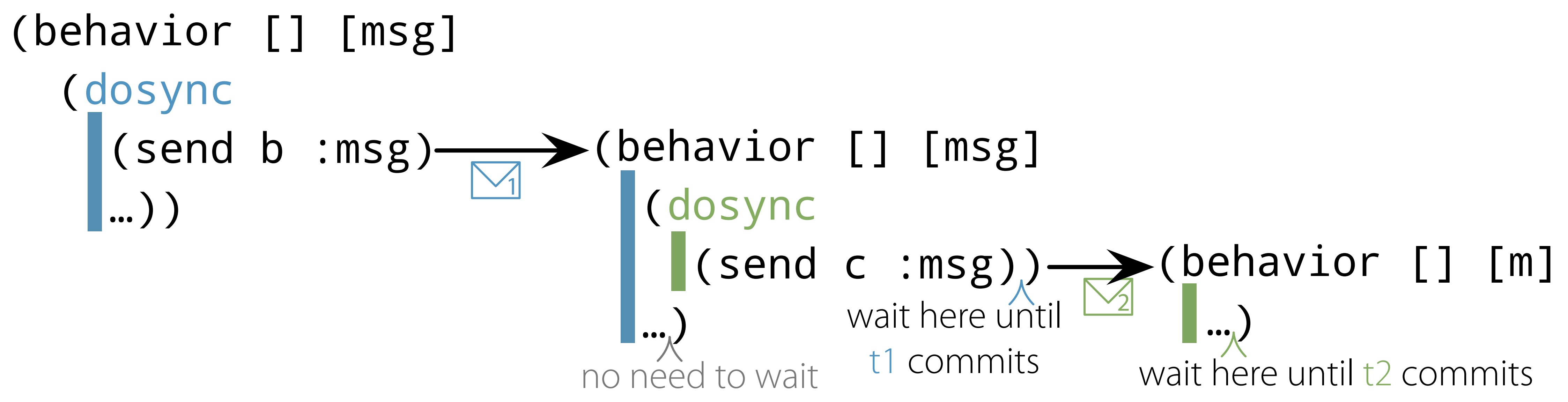
```
(behavior [] [msg]
  (dosync
   (send b :msg)──────▶(behavior [] [msg]
   …))                  …)
```

Benefits:

- serializable, deadlock free, race free
- finer-grained parallelism
  ⇒ higher speed-up



Message in transaction in tentative turn



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  (dosync
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   …))
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(behavior [] [msg]
 (dosync
  (send c :msg))
 …)
```

```
(behavior [] [m]
 …)
```