Towards Composable Concurrency Abstractions

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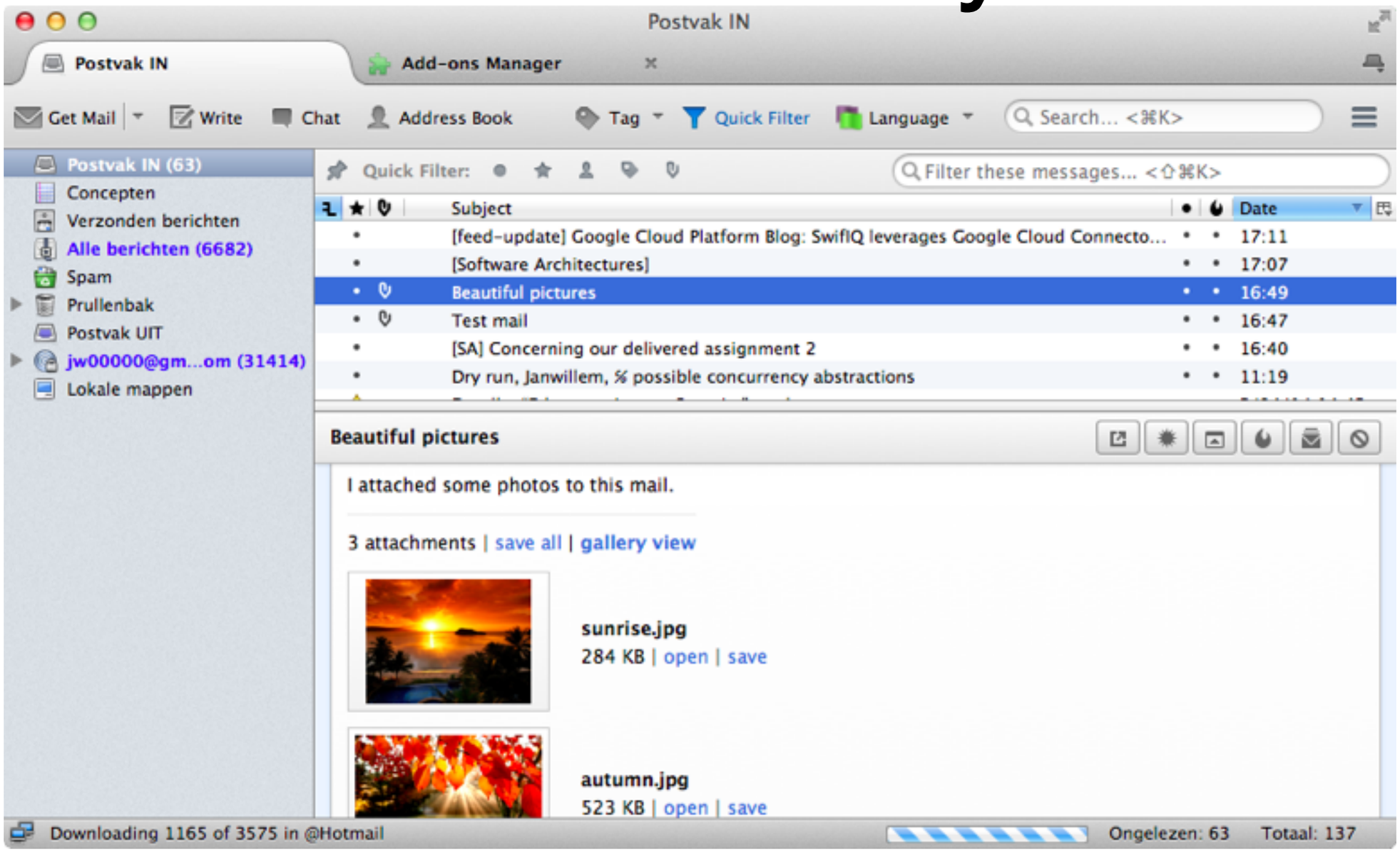
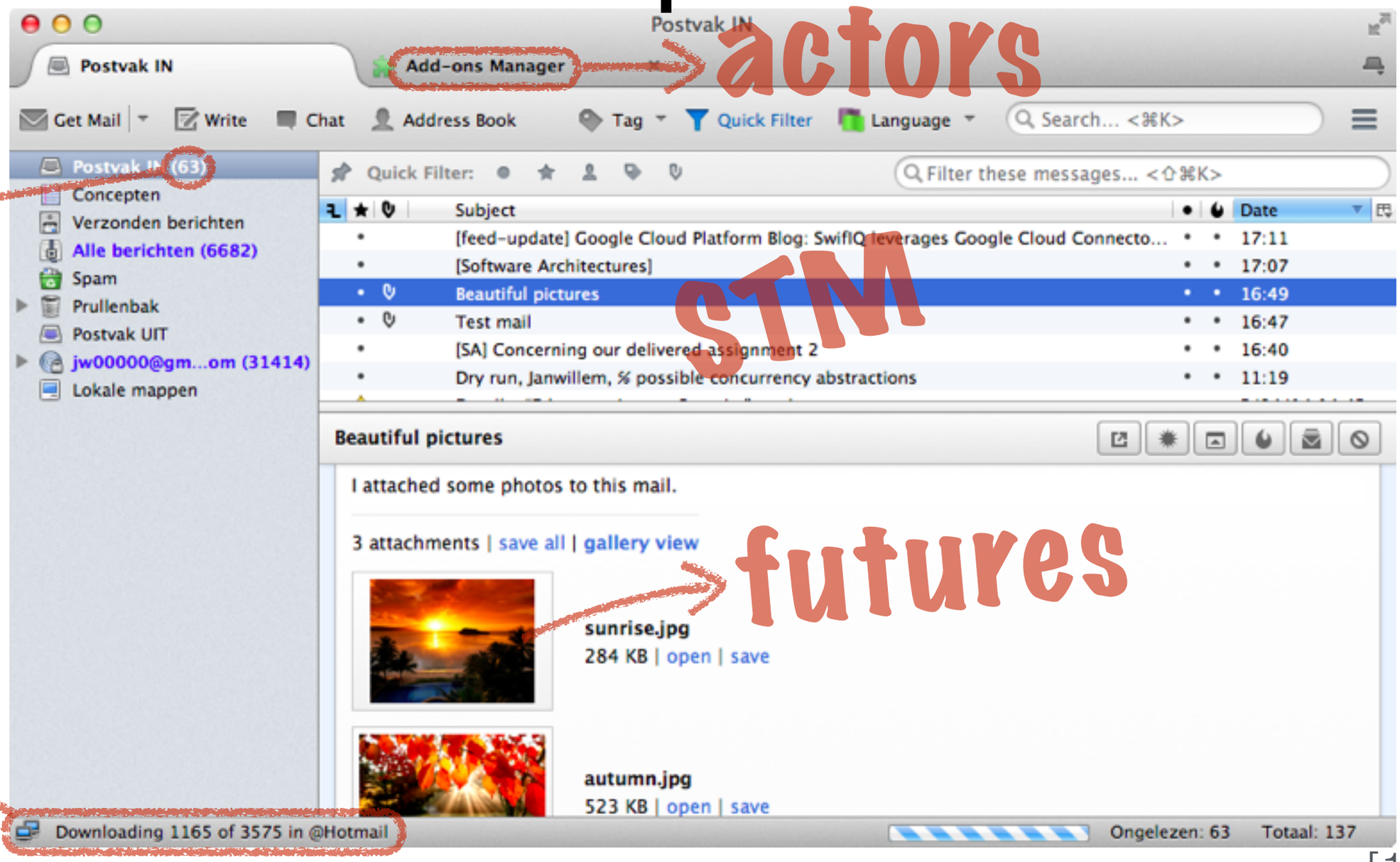
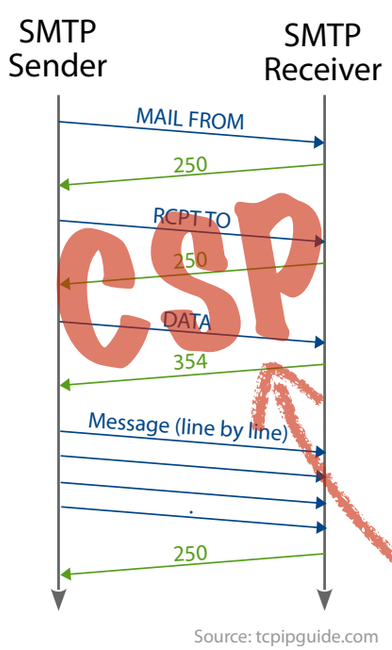
Complex GUI applications need concurrency



Different concurrency models for different requirements



atomic integer



Concurrency models are combined[1]

[1] Samira Tasharofi, Peter Dinges, and Ralph Johnson. Why Do Scala Developers Mix the Actor Model with Other Concurrency Models? In Proc. of ECOOP'13, Montpellier, France, 2013.

Can concurrency models be **combined** correctly?

Are they **composable**?

“composable”?

Criteria:[2]

- **Safety**: partial correctness
  correct input → ~~incorrect output~~
- **Liveness**: termination
  correct input terminates

correct input
↓ eventually
correct output

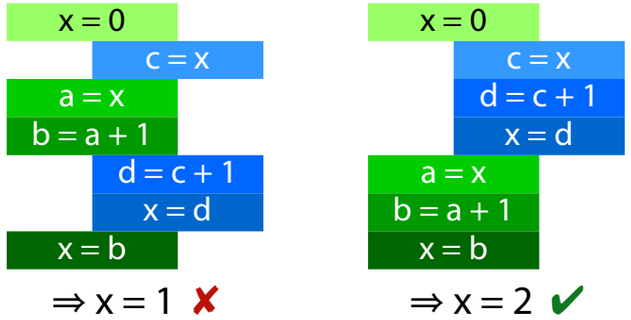
Two models are **composable** if combining them cannot produce *new* safety or liveness issues.

[2] Leslie Lamport. Proving the Correctness of Multiprocess Programs. IEEE Transactions on Software Engineering, SE-3(2):125–143, 1977.

Safety and liveness issues

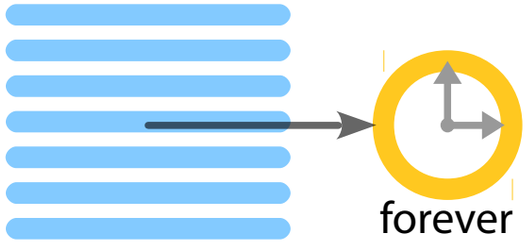
Safety:

→ **Race conditions**: incorrect results caused by bad interleavings



Liveness:

→ **Deadlocks**: introduced by blocking operations ⊗



→ **Livelocks**: code is re-executed under a certain condition ↻

Concurrency models

- Atomics
- Actors & Agents
- Software Transactional Memory (STM)
- Futures & Promises
- Communicating Sequential Processes (CSP)

→ Clojure

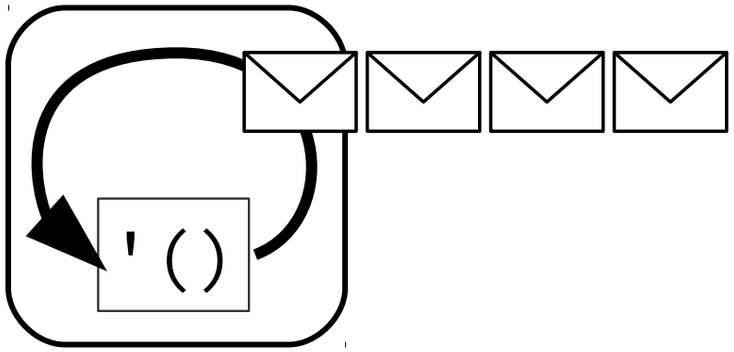
Atomic variables

```
(def unread-mails (atom 15))
(println (deref unread-mails))
(reset! unread-mails 0)
(swap! unread-mails inc)
```

	atoms
create	`atom`
read	`deref`
write	`reset!`
	`swap!` ↺

Agents

```
(def notifications (agent '()))
(println (deref notifications))
(send notifications
    (fn [msgs] (cons "Hello!" msgs)))
(await notifications)
```



	atoms	agents
create	`atom`	`agent`
read	`deref`	`deref`
write	`reset!`	
	`swap!` ↺	`send`
other		`await` ⊗

Software Transactional Memory

```
(def mail (ref {:subject "Hi!"}))
(dosync
    (println (deref mail))
    (ref-set mail {:subject "Hello!"})
    (alter mail (fn [m] (assoc m :subject "Hey!"))))
```

	atoms	agents	STM
create	atom	agent	ref
read	deref	deref	deref
write	reset!		ref-set
	swap! ↺	send	alter
block			dosync ↺
other		await ⊗	

Safety issues

Safety

used in	atoms	agents	STM	futures promises	CSP
atoms	✘	✘	✘	✘	✘
agents	✔	✔	✔	✔	✔
STM	✘	✔	✔	✘	✘
futures promises	✔	✔	✔	✔	✔
CSP	✔	✔	✔	✔	✔

```
(def notifications (agent '()))
(def unread-mails (atom 0))
(swap! unread-mails
  (fn [n]
    (send notifications
      (fn [msgs] (cons "New mail!" msgs)))
    (inc n)))
```

```
(def notifications (agent '()))
(def mail (ref {:subject "Hi" :archived false}))
(dosync
  (ref-set mail (assoc @mail :archived true))
  (send notifications
    (fn [msgs] (cons (str "Archived mail "
                          (:subject @mail)) msgs))))
```

Outer model re-executes } ⇒ **bad interleavings**

Inner model irrevocable actions } ⇒ **unsafe**

Futures & Promises

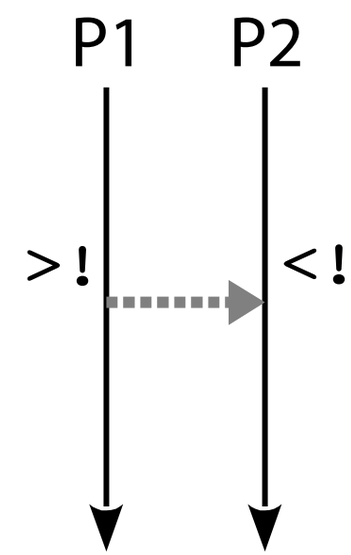
```
(def thumbnail (future (generate-thumbnail “attach.pdf”)))
(println (deref thumbnail))

(def p (promise))
(deliver p 2)
(println (deref p))
```

	atoms	agents	STM	futures	promises
create	atom	agent	ref	future	promise
read	deref	deref	deref	deref ⊗	deref ⊗
write	reset!		ref-set		deliver
	swap! ↺	send	alter		
block			dosync ↺		
other		await ⊗			

Communicating Sequential Processes

```
(def incoming-mails (chan))
(go
   (println (<! incoming-mails))
(go
   (>! incoming-mails {:subject “Hi!”}))
```



	atoms	agents	STM	futures	promises	CSP
create	atom	agent	ref	future	promise	chan
read	deref	deref	deref	deref ⊗	deref ⊗	<! ⊗
write	reset!		ref-set		deliver	>! ⊗
	swap! ↺	send	alter			
block			dosync ↺			go
other		await ⊗				

Liveness issues

Liveness

used in	atoms	agents	STM	futures promises	CSP
atoms	✔	✔	✔	✔	✘
agents	✔	✔	✔	✘	✘
STM	✔	✔	✔	✔	✘
futures promises	✔	✘	✔	✘	✘
CSP	✔	✘	✔	✔	✘

```
(def mails (ref '()))
(def incoming-mails (chan))
(dosync
  (ref-set mails
    (cons (<!! incoming-mails) @mails))
```

```
(def p (promise))
(def ag (agent 0))
```

Thread 1: Thread 2:

```
(deref p)          (deliver p 2)                ✔
```

```
(send ag                          (send ag                    ✘
  (fn [_] (deref p))                (fn [_] (deliver p 2)))
```

Inner model blocks
Outer model doesn't expect this } **⇒ possible deadlock**

Study Clojure

Safety

used / in	atoms	agents	STM	futures promises	CSP
atoms	✘	✘	✘	✘	✘
agents	✔	✔	✔	✔	✔
STM	✘	✔	✔	✘	✘
futures promises	✔	✔	✔	✔	✔
CSP	✔	✔	✔	✔	✔

Liveness

used / in	atoms	agents	STM	futures promises	CSP
atoms	✔	✔	✔	✔	✘
agents	✔	✔	✔	✘	✘
STM	✔	✔	✔	✔	✘
futures promises	✔	✘	✔	✘	✘
CSP	✔	✘	✔	✔	✘

Unsafe when:
Outer model re-executes
Inner model irrevocable actions

Possible deadlock when:
Inner model blocks
Outer model doesn't expect this

✘ proven by counter-example
✔ "proof" by argument

Solutions & ideas

1. Existing solutions

E.g. **`send`** to agent in **`dosync`** = delayed (Clojure)

2. Extend existing solutions

→ Delay deliver of promise in transaction

→ Disallow reading futures/promises *in* agent (↔ *before*)

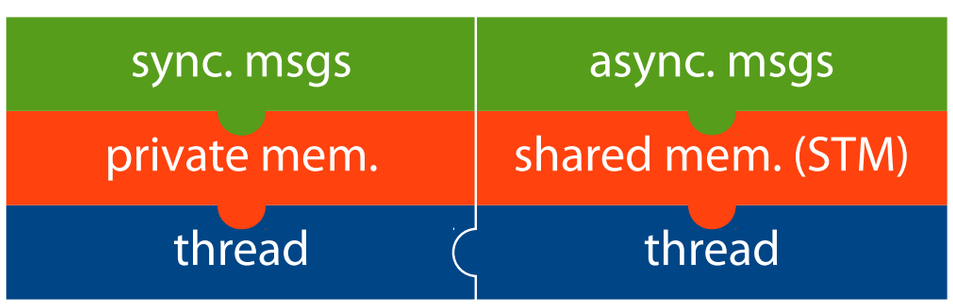
3. Future research

Building blocks

Future direction

Now:

Goal:

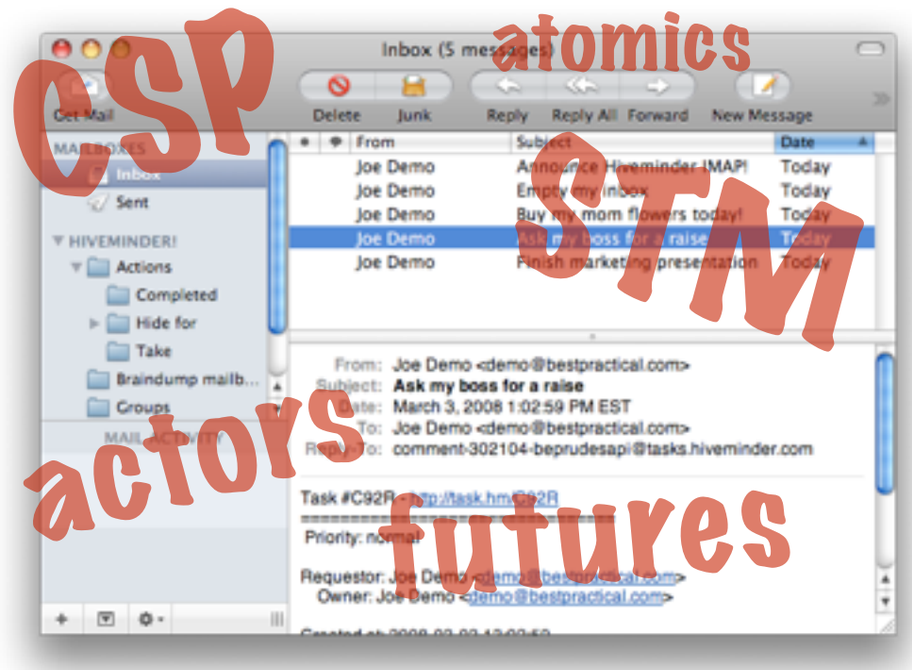


- safe, uniform, composition of components
- prevent unsafe combinations:
  - irrevocable actions in re-executing blocks (e.g. sync msgs in STM transaction)
  - blocking operations in blocks that guarantee progress (e.g. @future in agent)

Open questions & future work

- Proof ✔s
- Formal framework for all models?

Summary



Safety

	atoms	agents	refs	fut/prom	channel
atoms	✗	✗	✗	✗	✗
agents	✓	✓	✓	✓	✓
refs	✗	✓	✓	✗	✗
fut/prom	✓	✓	✓	✓	✓
channel	✓	✓	✓	✓	✓

Liveness

	atoms	agents	refs	fut/prom	channel
atoms	✓	✓	✓	✓	✗
agents	✓	✓	✓	✗	✗
refs	✓	✓	✓	✓	✗
fut/prom	✓	✗	✓	✗	✗
channel	✓	✗	✓	✓	✗