Ambient References:
Object Designation in Mobile Ad Hoc Networks

Tom Van Cutsem

Promotors:
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Brussels, Belgium

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Roadmap

Roadmap

Motivation

Mobile ad hoc networks

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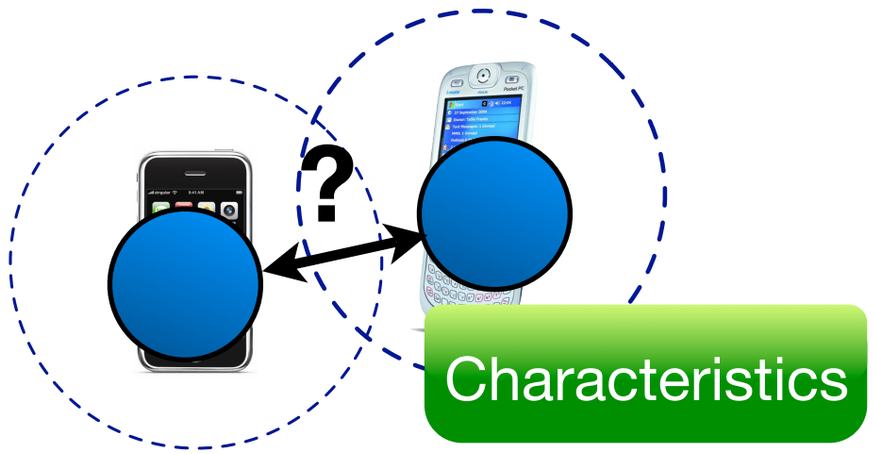
Coordination



Mobile ad hoc networks

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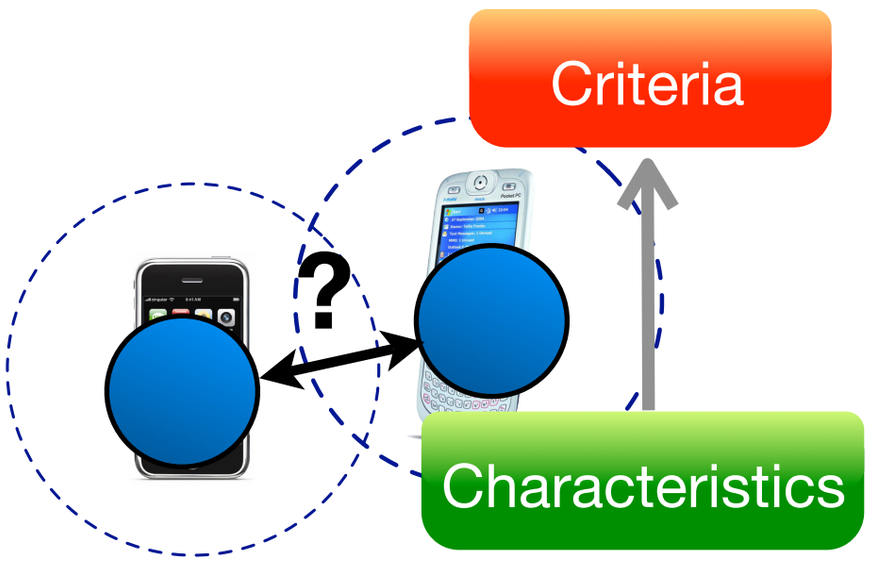

Mobile ad hoc networks

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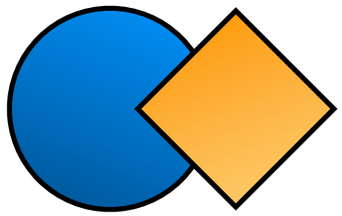
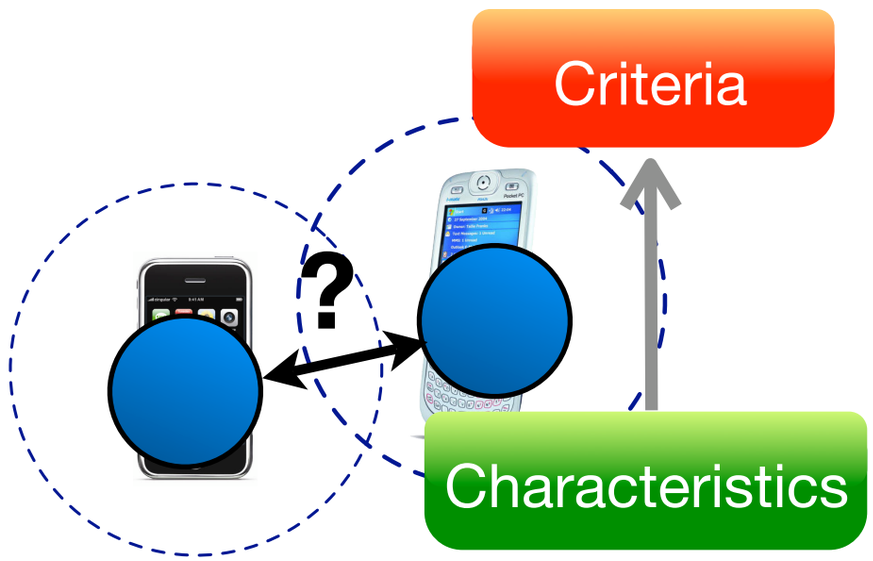


Object-event impedance mismatch

Coordination



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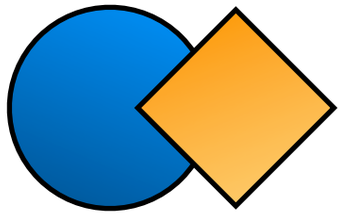

Object-event impedance mismatch

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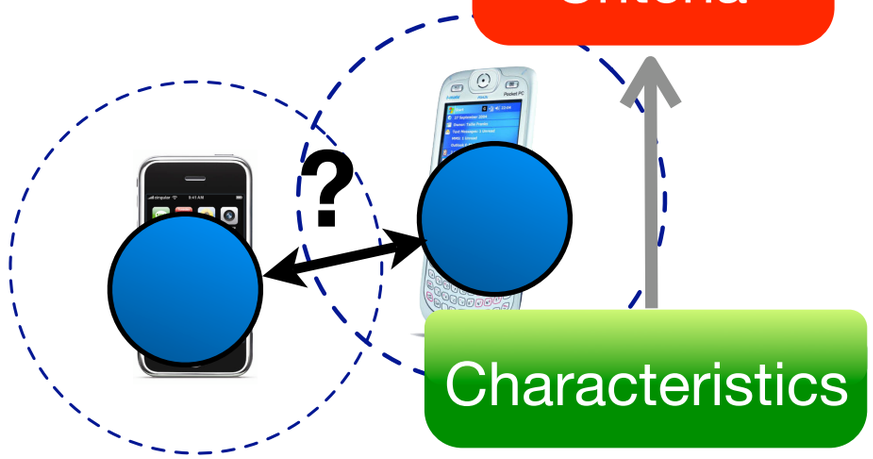

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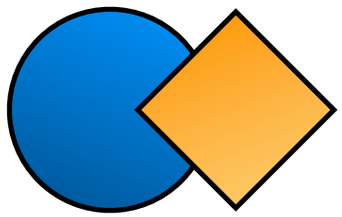

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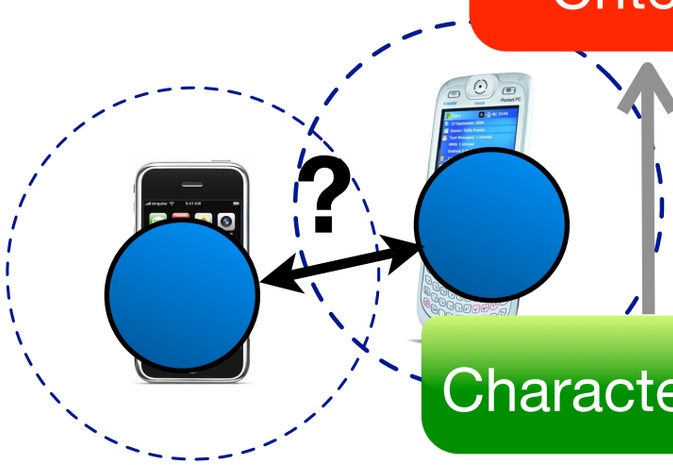

Characteristics

Mobile ad hoc networks

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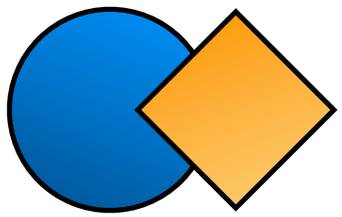

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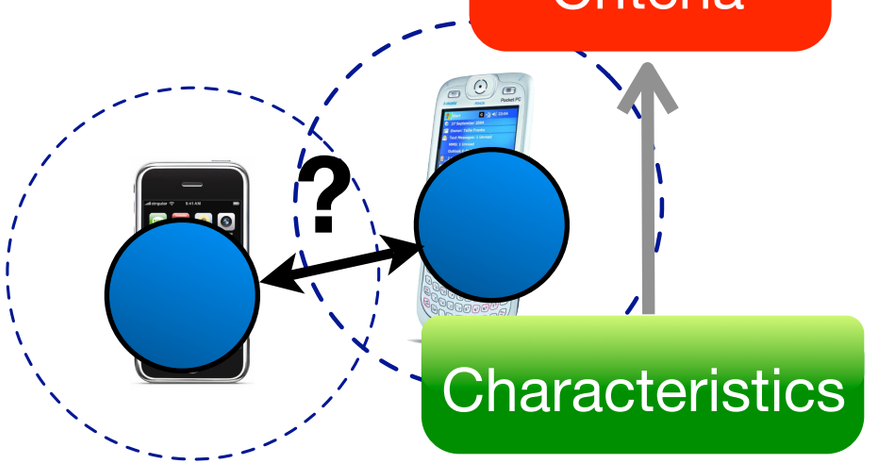

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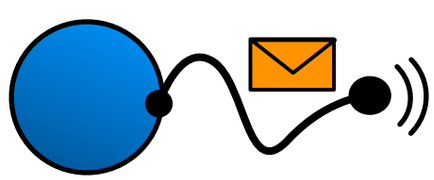

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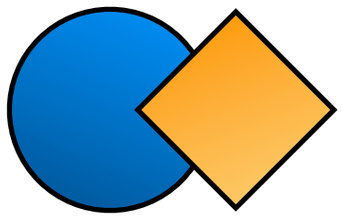

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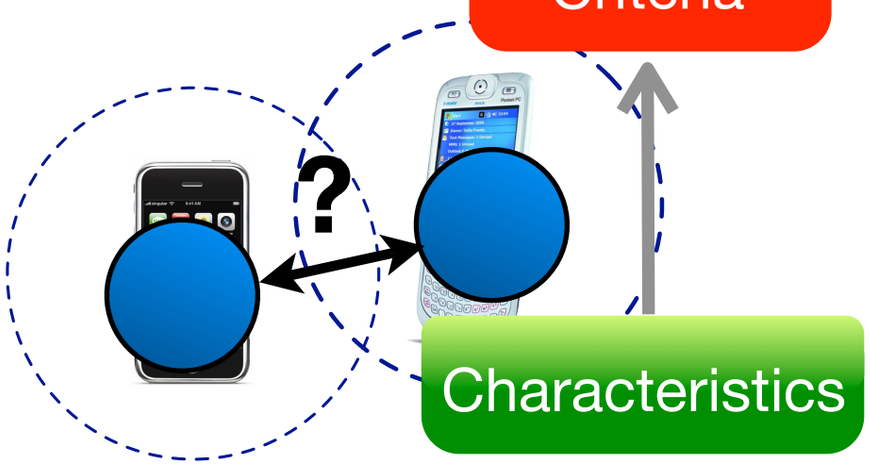

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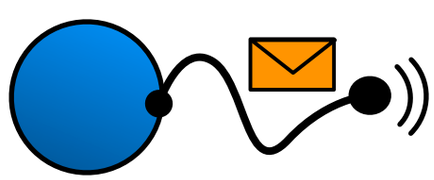
Language

Language Feature



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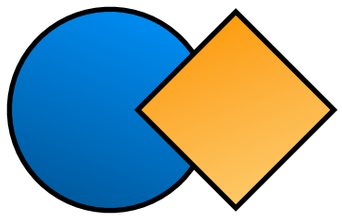

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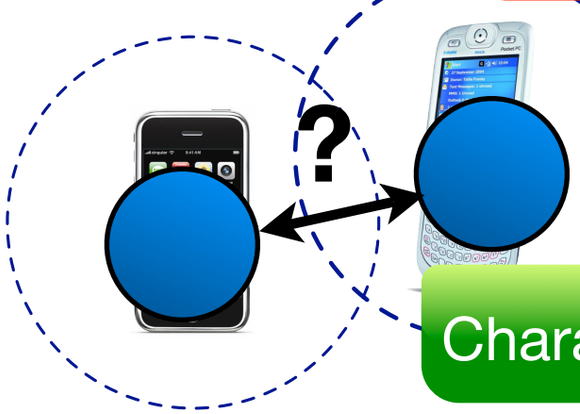

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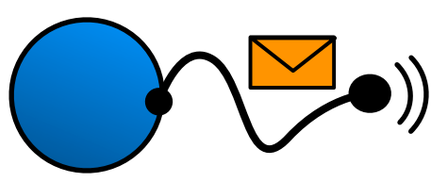

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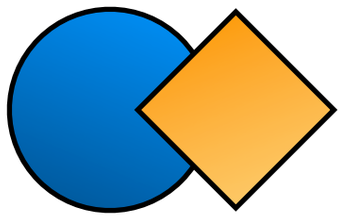

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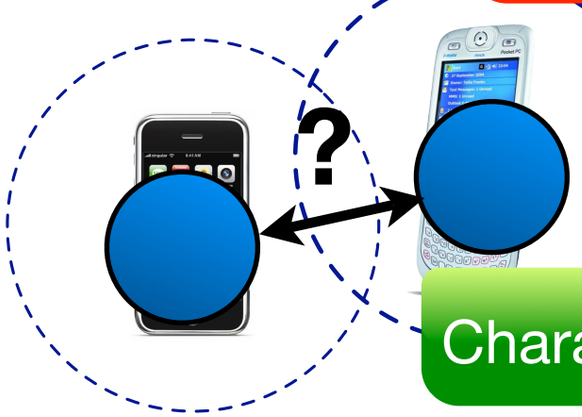

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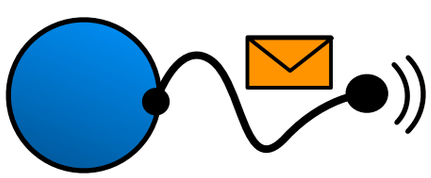

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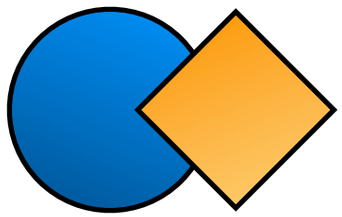

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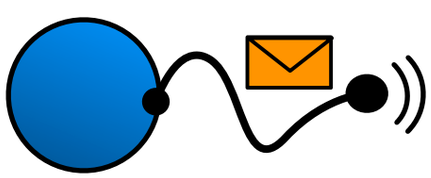

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Context & Problem Statement

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Mobile Ad Hoc Networks

Networks composed of **mobile** devices which communicate **wirelessly**

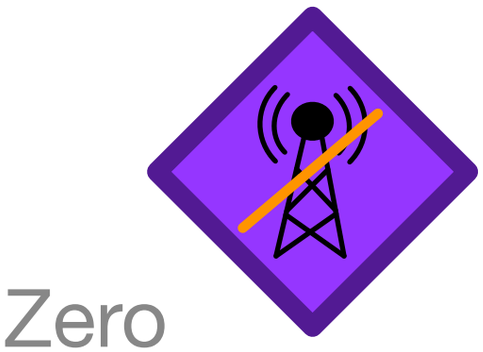
Ubiquitous Computing

Mobile Ad Hoc Networks

Networks composed of **mobile** devices which communicate **wirelessly**

Mobile Ad Hoc Networks

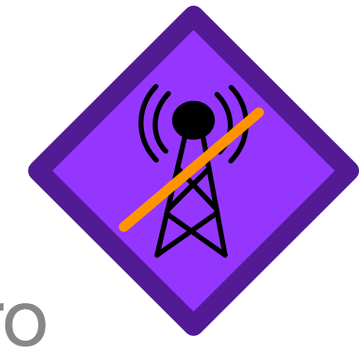
Networks composed of **mobile** devices which communicate **wirelessly**



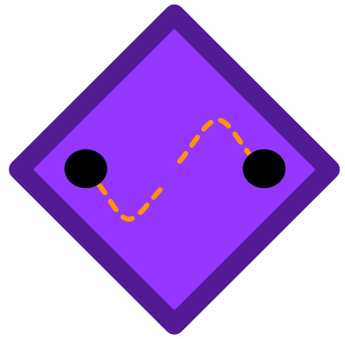
Zero
Infrastructure

Mobile Ad Hoc Networks

Networks composed of **mobile** devices which communicate **wirelessly**



Zero Infrastructure



Volatile Connections

Problem Statement

- Ambient-oriented Programming [Dedecker06]: traditional OOP does not scale in MANETs. How can we:
  - **designate** objects, with zero infrastructure?
  - **communicate** with objects, across volatile connections?
- Answer: event-based communication
- But: such communication is **fundamentally** not object-oriented

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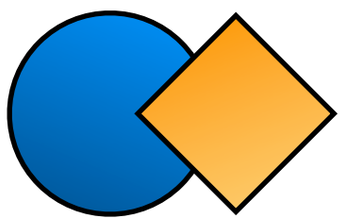
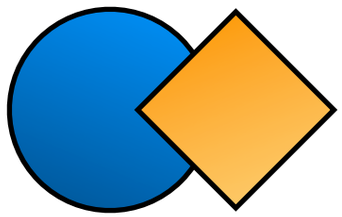
object-event impedance mismatch



Roadmap

Motivation



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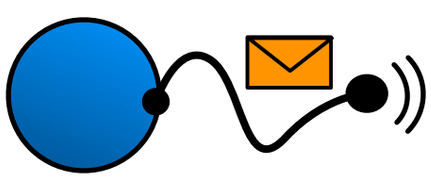

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Coordination in Mobile ad hoc Networks

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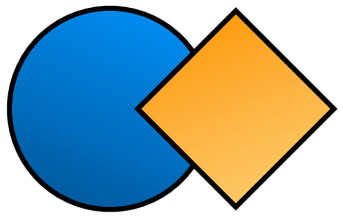

Object-event impedance mismatch

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Coordination in Mobile Ad Hoc Networks

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Coordination in Mobile Ad Hoc Networks

uMaMa

Discovery

Coordination in Mobile Ad Hoc Networks

uMaMa

Discovery

Communication

Coordination in Mobile Ad Hoc Networks

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Discovery Communication Synchronisation

Coordination in Mobile Ad Hoc Networks

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Discovery Communication Synchronisation

Coordination in Mobile Ad Hoc Networks

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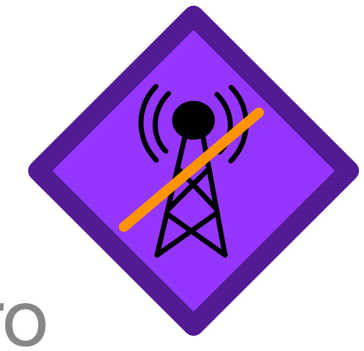
Discovery Communication Synchronisation Failure handling

Criteria for Coordination in MANETs



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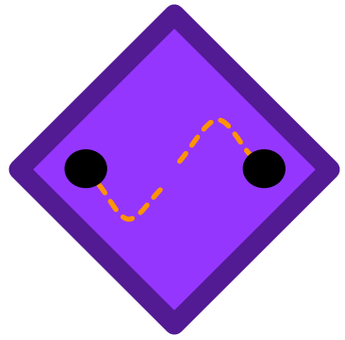
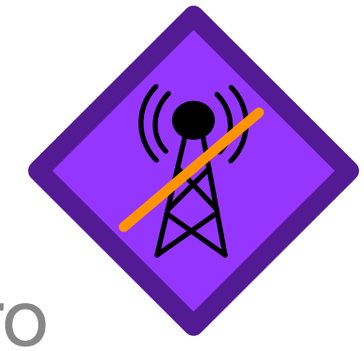


Volatile Connections

Criteria for Coordination in MANETs



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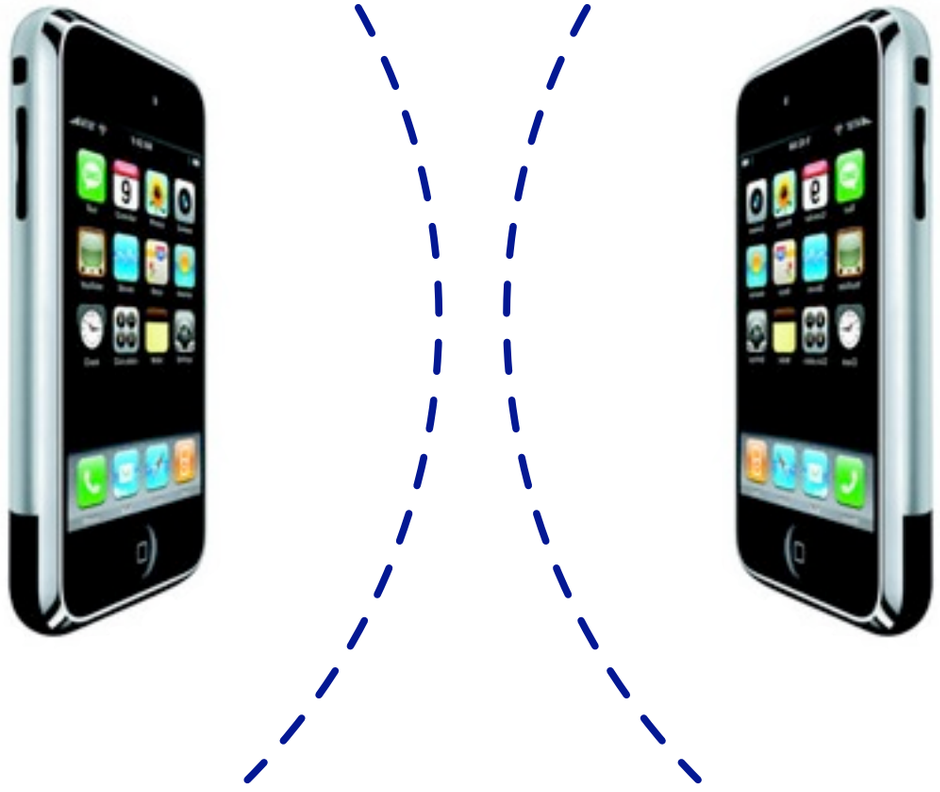
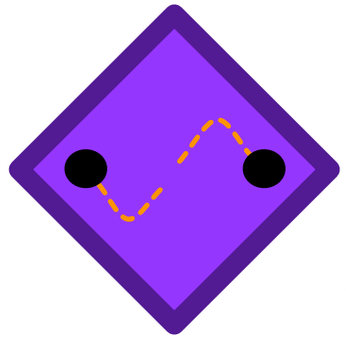
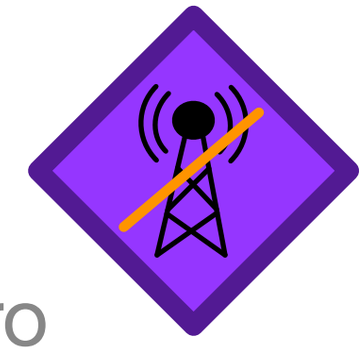




Volatile
Connections

Decentralised Discovery

Criteria for Coordination in MANETs



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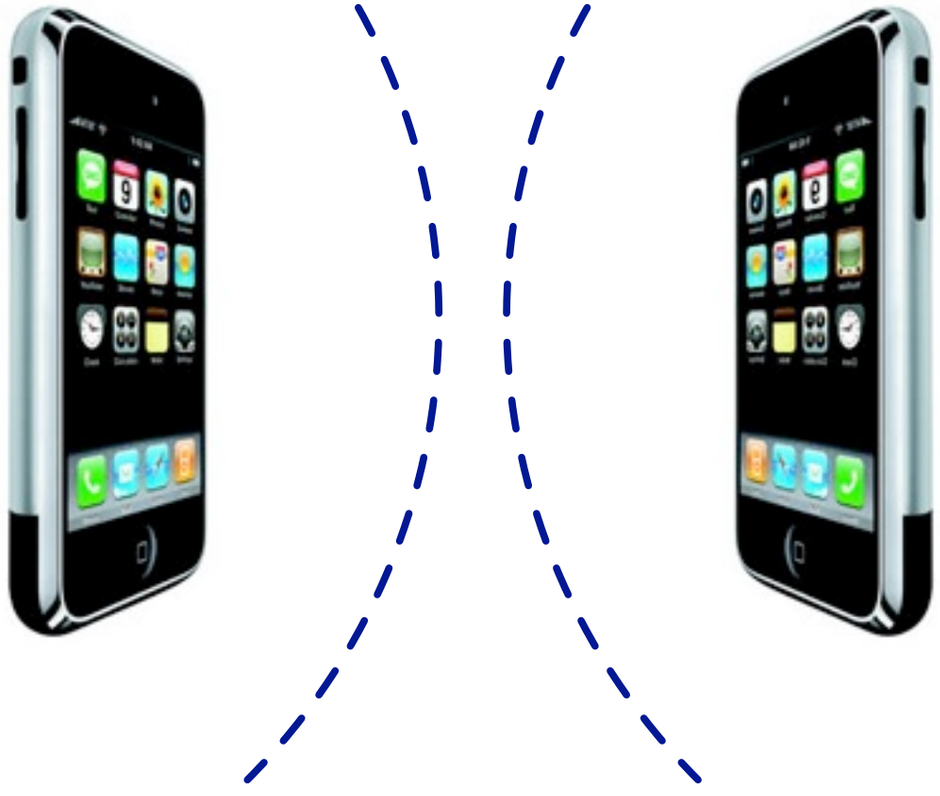
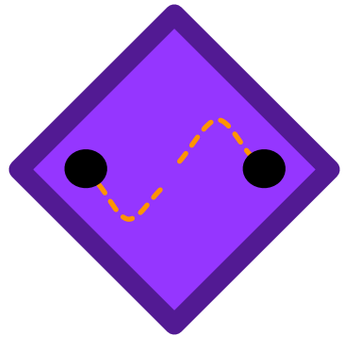


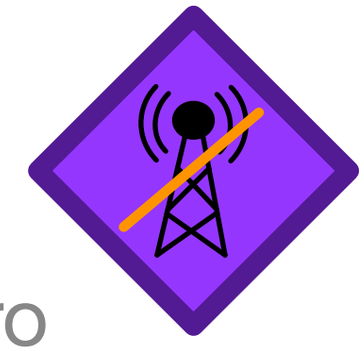


Volatile
Connections

Decentralised Discovery

Space & arity decoupled
communication

Criteria for Coordination in MANETs



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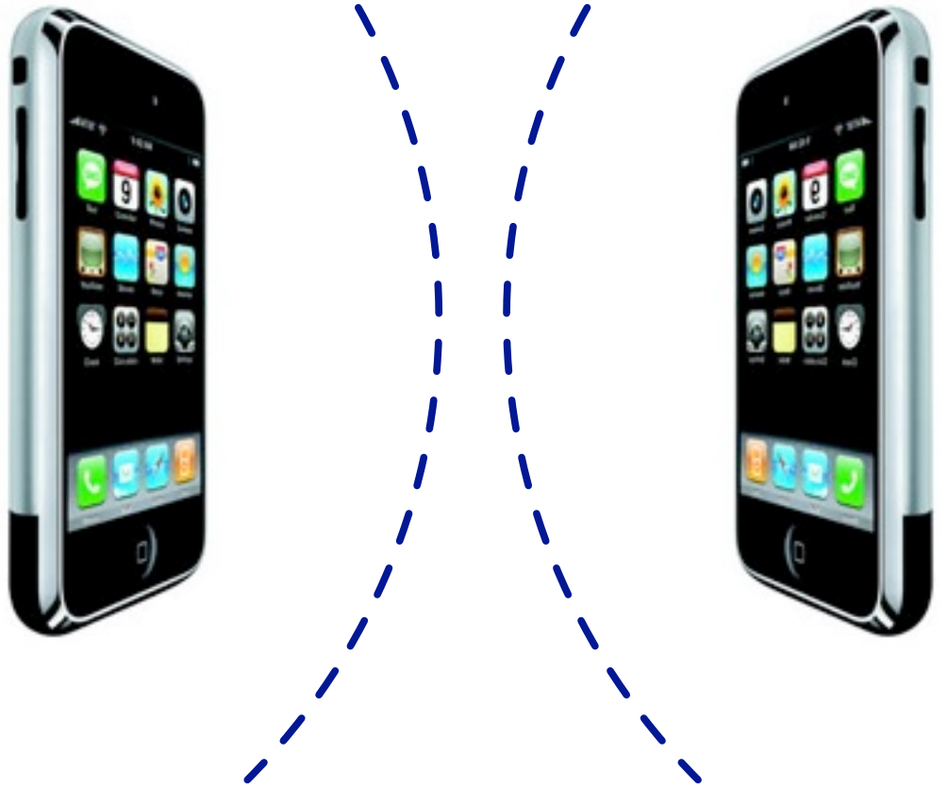
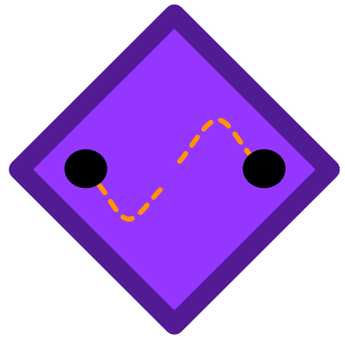


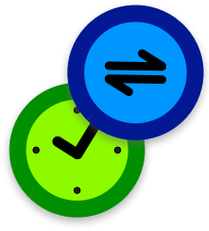


Volatile Connections

Decentralised Discovery

Space & arity decoupled communication

Time & synchronisation decoupled communication



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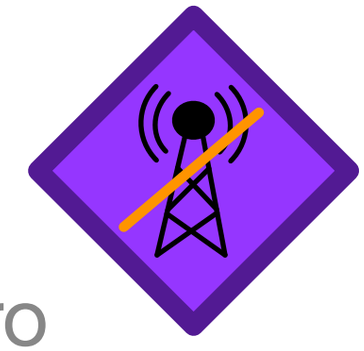

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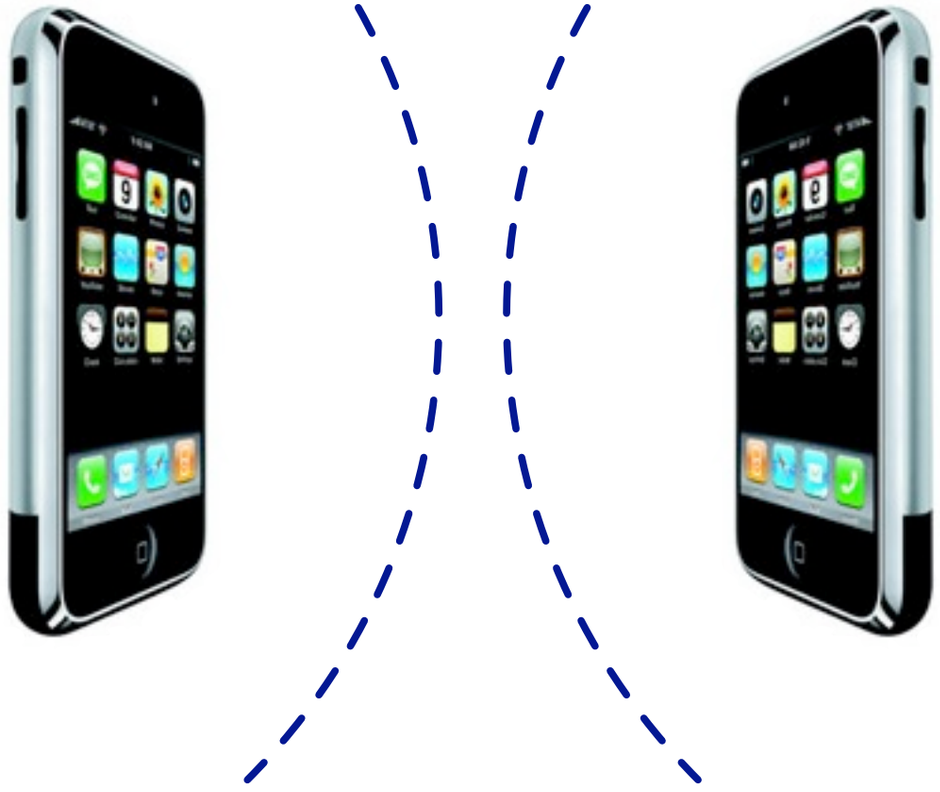

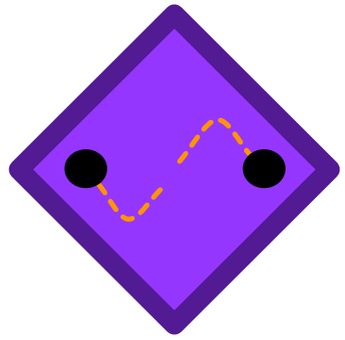

Volatile Connections

Decentralised Discovery

Time & synchronisation decoupled communication

Space & arity decoupled communication

Connection-independent Failure handling

Survey of Related Work

	Decoupling in				Failure	Decentr.	Message
	Time	Space	Synchronisation	Arity	Handling	Discovery	Passing
Languages for Local Area Networks							
Emerald	N (Error)	N (Address)	N (RPC)	N	Exc.	N	Y
Obliq	N (Error)	N (Address)	N (RPC)	N	Exc.	N	Y
ABCL	Y (Buffer)	N (Address)	Sender only	N	N	N	Y
Languages for Wide Area Networks							
Erlang	Y (Buffer)	N (Address)	Sender only	N	React	N	Y
Argus	N (Error)	N (Address)	N(RPC)	N	Exc.	N	Y
Janus	Y (Blocks)	N (Address)	N (Logic Var)	N	N	N	N
Salsa	Y (Buffer)	N (Address)	Y (Async Msg)	N	N	N	Y
E	N (Error)	N (Address)	Y (Async Msg)	N	React	N	Y
Distributed Oz	Y (Blocks)	N (Address)	N (Logic Var)	N	React	N	Y
Languages for Wireless Sensor Networks							
ActorNet	Y (Buffer)	N (Address)	Y (Async Msg)	Y	N	N	Y
SpatialViews	Y (Mediator)	Y (Discovery)	Y (Mediator)	Y	N	N	N
Models and Calculi for Wide Area Networks							
Actors	Y (Buffer)	N (URI)	Y (Async Msg)	N	N	N	Y
ActorSpace	Y (Buffer)	Y (Mediator)	Y (Async Msg)	Y	N	N	Y
Mobile Ambients	Y (Mediator)	Y (Mediator)	Sender only	N	N	N	N
Tuple Space Middleware for Ad Hoc Networks							
LIME	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	React	Y	N
TOTA	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	React	Y	N
MARS	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	Lease	N	N
Middleware for Nomadic Networks							
Rover	Y (Buffer)	N (Address)	Y (Async Msg)	N	React	N	Y
JINI	N (Error)	Y (Discovery)	N (RPC)	N	Lease	Y	Y
Publish-Subscribe Middleware for Ad Hoc Networks							
EMMA	N (Lost)	Y (Mediator)	Y (Mediator)	Y	Lease	Y	N
LPS	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	N	N	N
STEAM	N (Lost)	Y (Mediator)	Y (Mediator)	Y	N	N	N
M2MI	N (Lost)	Y (Broadcast)	Y (Async Msg)	Y	N	N	Y
one.world	N (Lost)	Y (Discovery)	Y (Mediator)	Y	Lease	Y	N

Survey of Related Work

	Decoupling in				Failure Handling	Decentr. Discovery	Message Passing
	Time	Space	Synchronisation	Arity			
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Janus	Y (Blocks)	N (Address)	N (Logic Var)	N	N	N	N
Salsa	Y (Buffer)	N (Address)	Y (Async Msg)	N	N	N	Y
E	N (Error)	N (Address)	Y (Async Msg)	N	React	N	Y
Distributed Oz	Y (Blocks)	N (Address)	N (Logic Var)	N	React	N	Y
Languages for Wireless Sensor Networks							
ActorNet	Y (Buffer)	N (Address)	Y (Async Msg)	Y	N	N	Y
SpatialViews	Y (Mediator)	Y (Discovery)	Y (Mediator)	Y	N	N	N
Models and Calculi for Wide Area Networks							
Actors	Y (Buffer)	N (URI)	Y (Async Msg)	N	N	N	Y
ActorSpace	Y (Buffer)	Y (Mediator)	Y (Async Msg)	Y	N	N	Y
Mobile Ambients	Y (Mediator)	Y (Mediator)	Sender only	N	N	N	N
Tuple Space Middleware for Ad Hoc Networks							
LIME	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	React	Y	N
TOTA	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	React	Y	N
MARS	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	Lease	N	N
Middleware for Nomadic Networks							
Rover	Y (Buffer)	N (Address)	Y (Async Msg)	N	React	N	Y
JINI	N (Error)	Y (Discovery)	N (RPC)	N	Lease	Y	Y
Publish-Subscribe Middleware for Ad Hoc Networks							
EMMA	N (Lost)	Y (Mediator)	Y (Mediator)	Y	Lease	Y	N
LPS	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	N	N	N
STEAM	N (Lost)	Y (Mediator)	Y (Mediator)	Y	N	N	N
M2MI	N (Lost)	Y (Broadcast)	Y (Async Msg)	Y	N	N	Y
one.world	N (Lost)	Y (Discovery)	Y (Mediator)	Y	Lease	Y	N

Survey of Related Work

	Decoupling in				Failure Handling	Decentr. Discovery	Message Passing
	Time	Space	Synchronisation	Arity			
Languages for Local Area Networks							
Emerald	N (Error)	N (Address)	N (RPC)	N	Exc.	N	Y
Obliq	N (Error)	N (Address)	N (RPC)	N	Exc.	N	Y
ABCL	Y (Buffer)	N (Address)	Sender only	N	N	N	Y
Languages for Wide Area Networks							
Erlang	Y (Buffer)	N (Address)	Sender only	N	React	N	Y
Argus	N (Error)	N (Address)	N(RPC)	N	Exc.	N	Y
Janus	Y (Blocks)	N (Address)	N (Logic Var)	N	N	N	N
Salsa	Y (Buffer)	N (Address)	Y (Async Msg)	N	N	N	Y
E	N (Error)	N (Address)	Y (Async Msg)	N	React	N	Y
Distributed Oz	Y (Blocks)	N (Address)	N (Logic Var)	N	React	N	Y
Languages for Wireless Sensor Networks							
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STEAM	N (Lost)	Y (Mediator)	Y (Mediator)	Y	N	N	N
M2MI	N (Lost)	Y (Broadcast)	Y (Async Msg)	Y	N	N	Y
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	Time	Space	Synchronisation	Arity	Handling	Discovery	Passing
Languages for Local Area Networks							
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Janus	Y (Blocks)	N (Address)	N (Logic Var)	N	N	N	N
Salsa	Y (Buffer)	N (Address)	Y (Async Msg)	N	N	N	Y
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OO Message Passing metaphor => bad decoupling

Survey of Related Work

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M2MI	N (Lost)	Y (Broadcast)	Y (Async Msg)	Y	N	N	Y
one.world	N (Lost)	Y (Discovery)	Y (Mediator)	Y	Lease	Y	N

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STEAM	N (Lost)	Y (Mediator)	Y (Mediator)	Y	N	N	N
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OO Message Passing metaphor => bad decoupling

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Salsa	Y (Buffer)	N (Address)	Y (Async Msg)	N	N	N	Y
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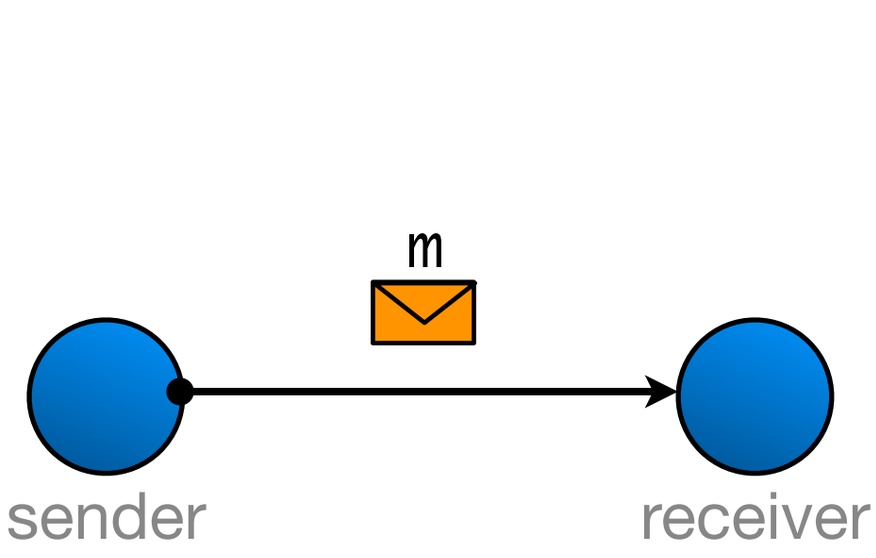
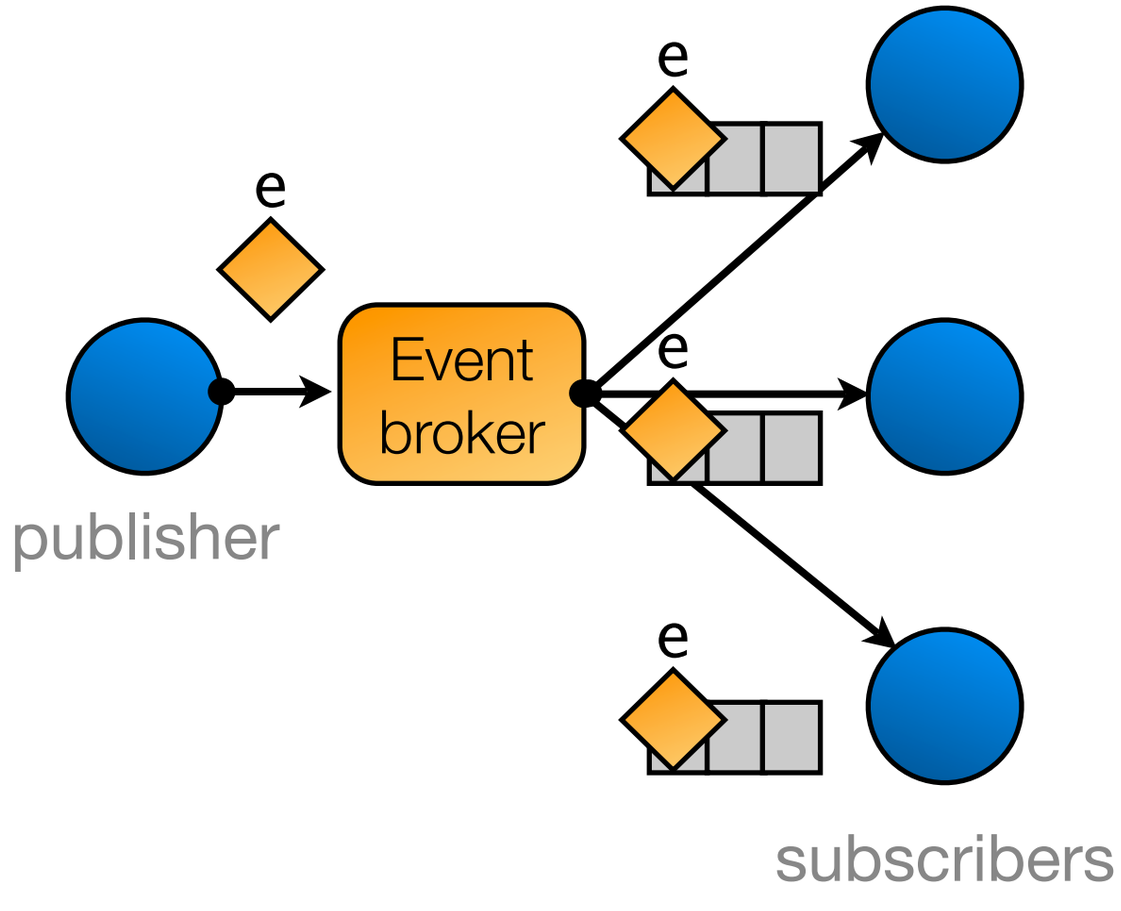
Middleware for Nomadic Networks							
Rover	Y (Buffer)	N (Address)	Y (Async Msg)	N	React	N	Y
JINI	N (Error)	Y (Discovery)	N (RPC)	N	Lease	Y	Y
Publish-Subscribe Middleware for Ad Hoc Networks							
EMMA	N (Lost)	Y (Mediator)	Y (Mediator)	Y	Lease	Y	N
LPS	Y (Mediator)	Y (Mediator)	Y (Mediator)	Y	N	N	N
STEAM	N (Lost)	Y (Mediator)	Y (Mediator)	Y	N	N	N
M2MI	N (Lost)	Y (Broadcast)	Y (Async Msg)	Y	N	N	Y
one.world	N (Lost)	Y (Discovery)	Y (Mediator)	Y	Lease	Y	N

OO Message Passing metaphor => bad decoupling

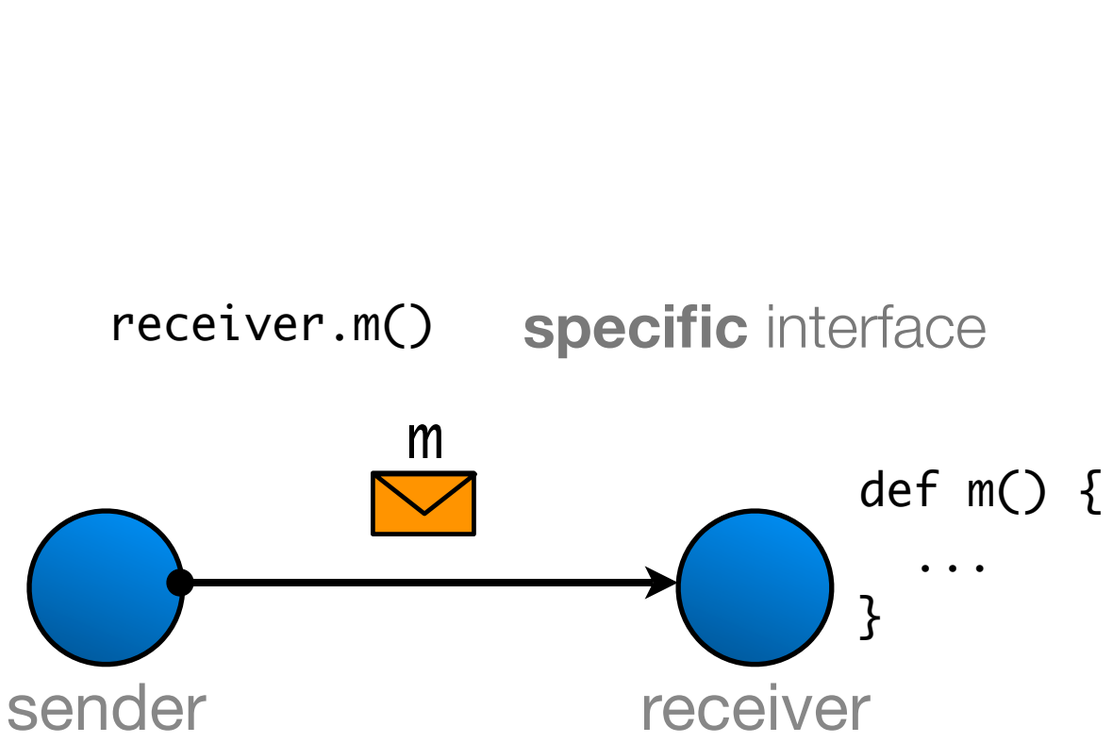
Pub/sub & Tuple spaces => better decoupling

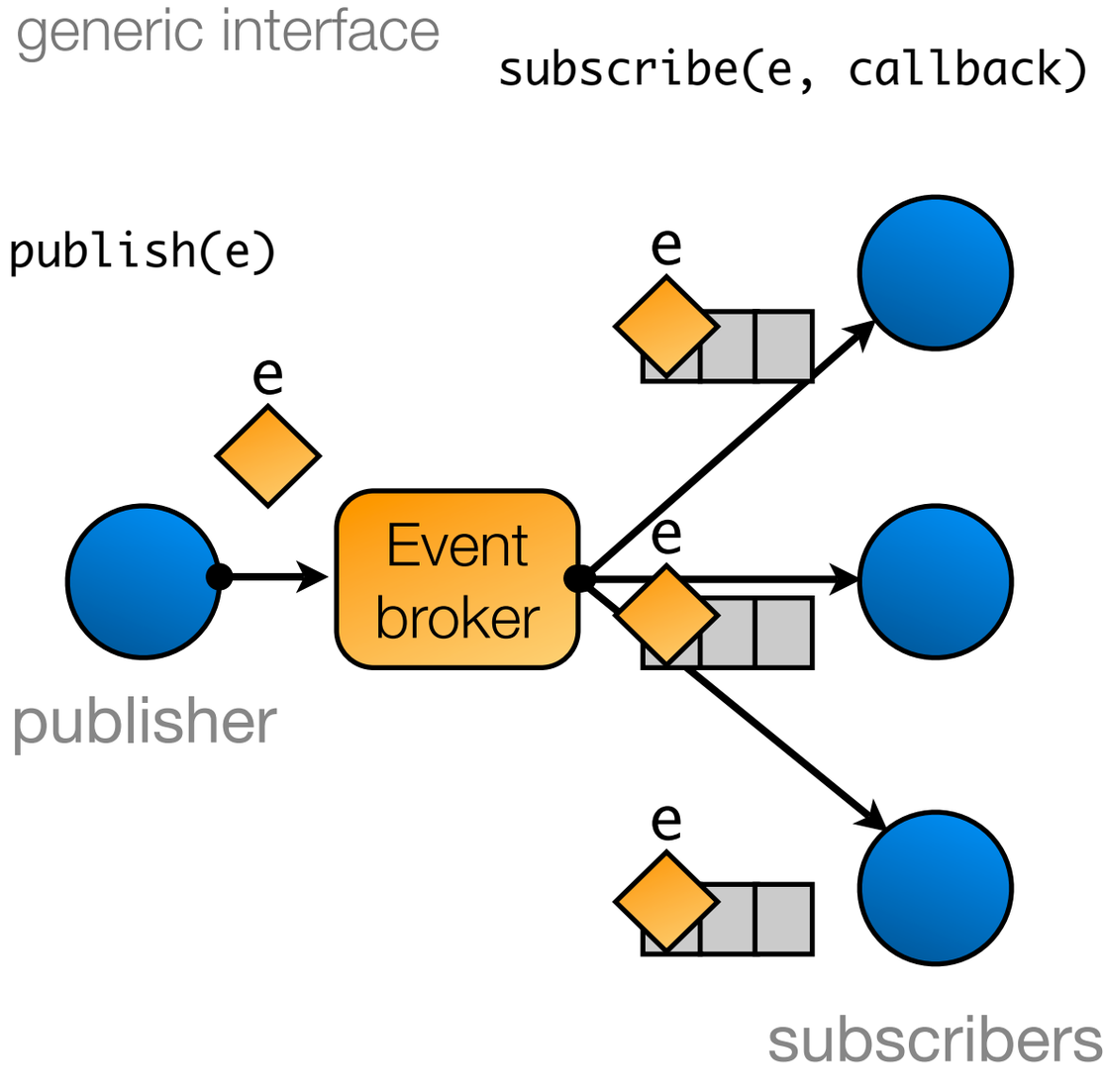
Object-event Impedance Mismatch



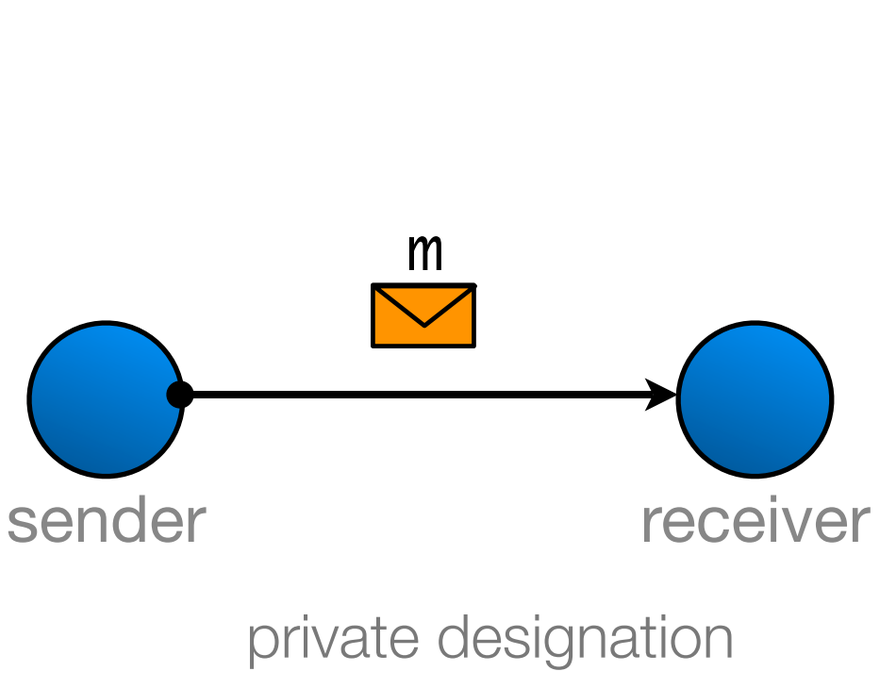


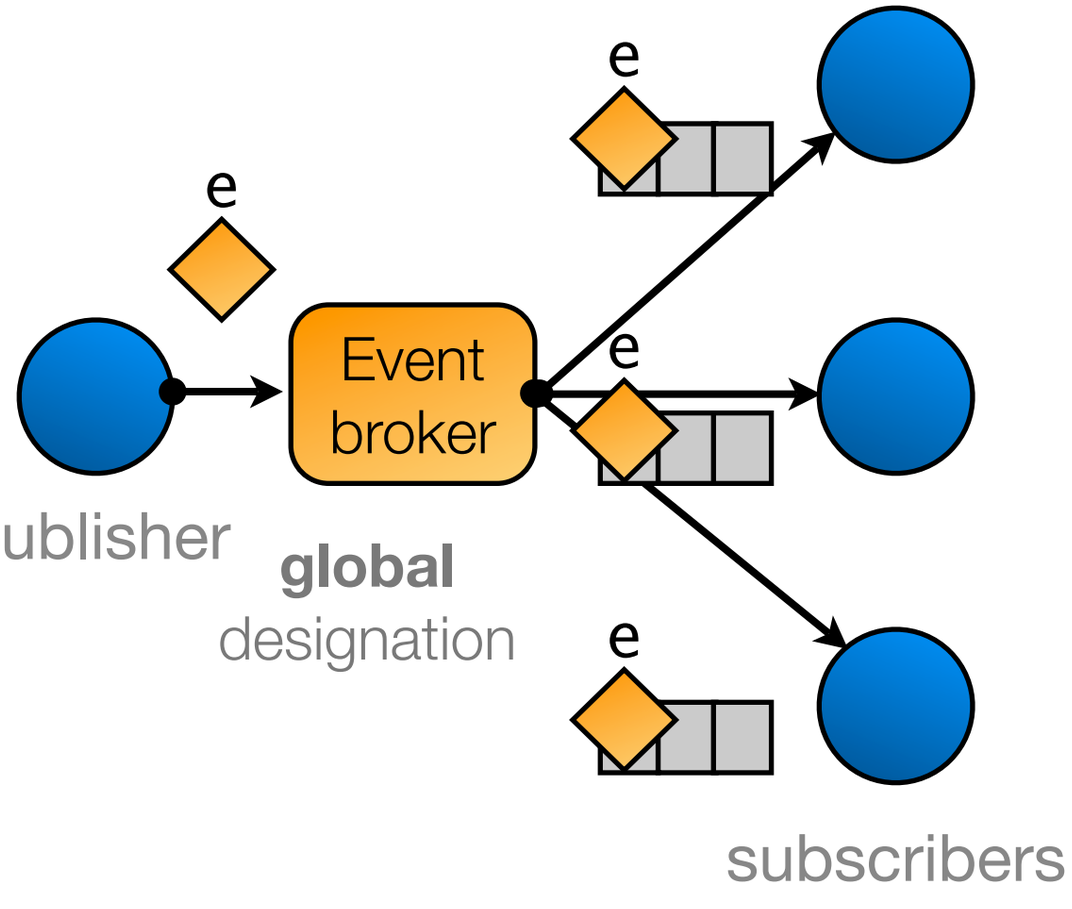
Object-event Impedance Mismatch





Object-event Impedance Mismatch





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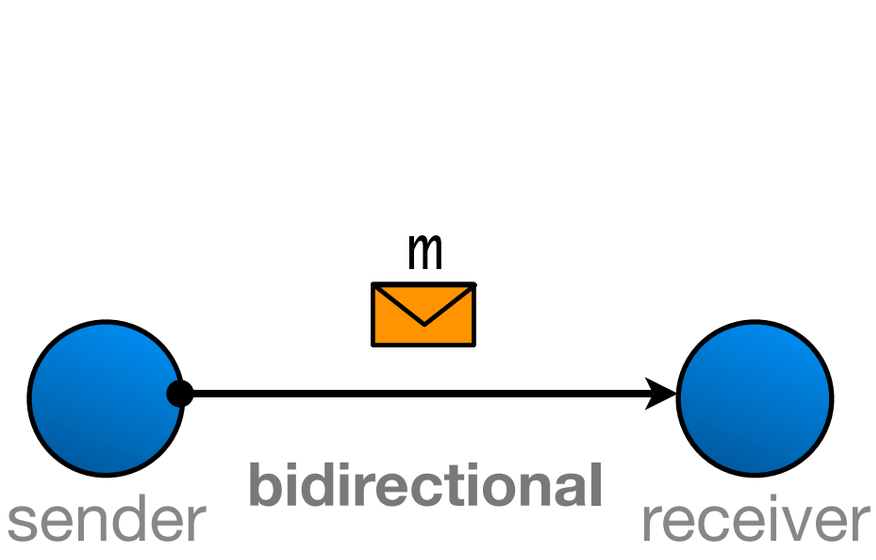
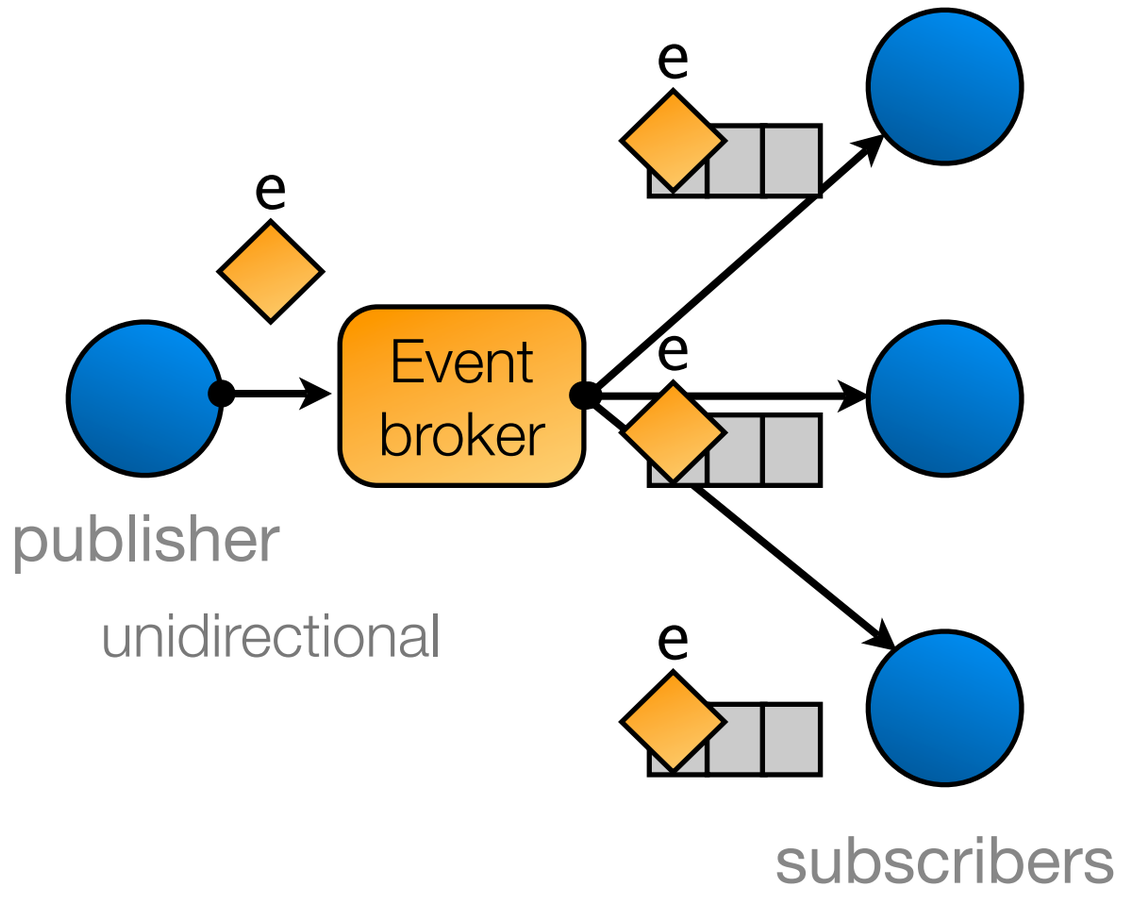
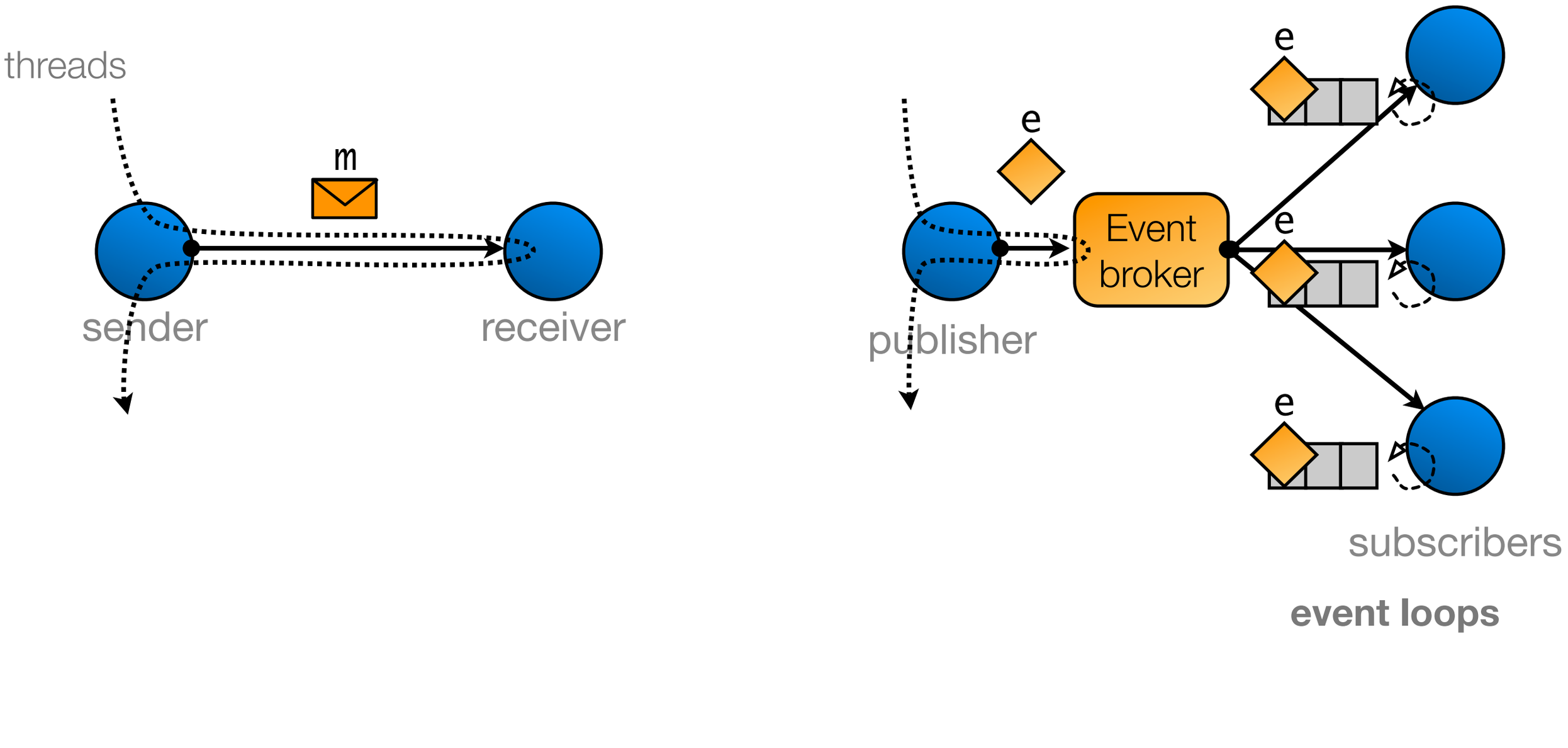


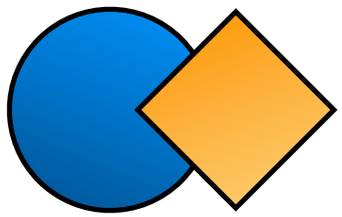


Object-event Impedance Mismatch



Roadmap

Motivation

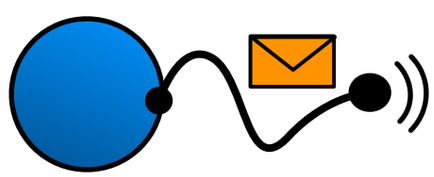


Object-event impedance mismatch

Coordination

Mobile ad hoc networks

Contribution



Ambient References

Validation

Evaluation

Implementation

Coordination in Mobile ad hoc Networks

Motivation

Object-event impedance mismatch

Coordination

Mobile ad hoc networks

Contribution

AMBIENTTALK

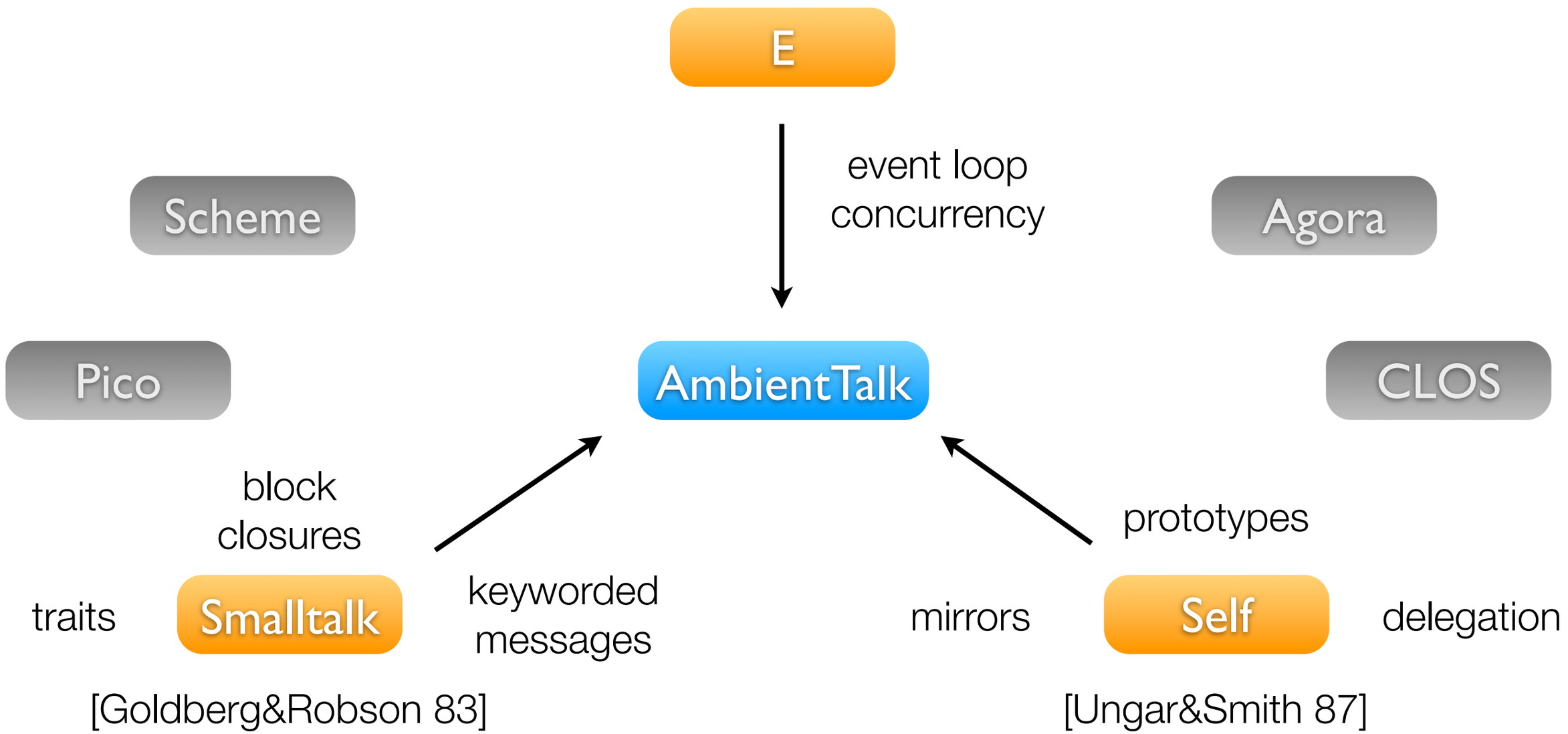
Ambient References

Validation

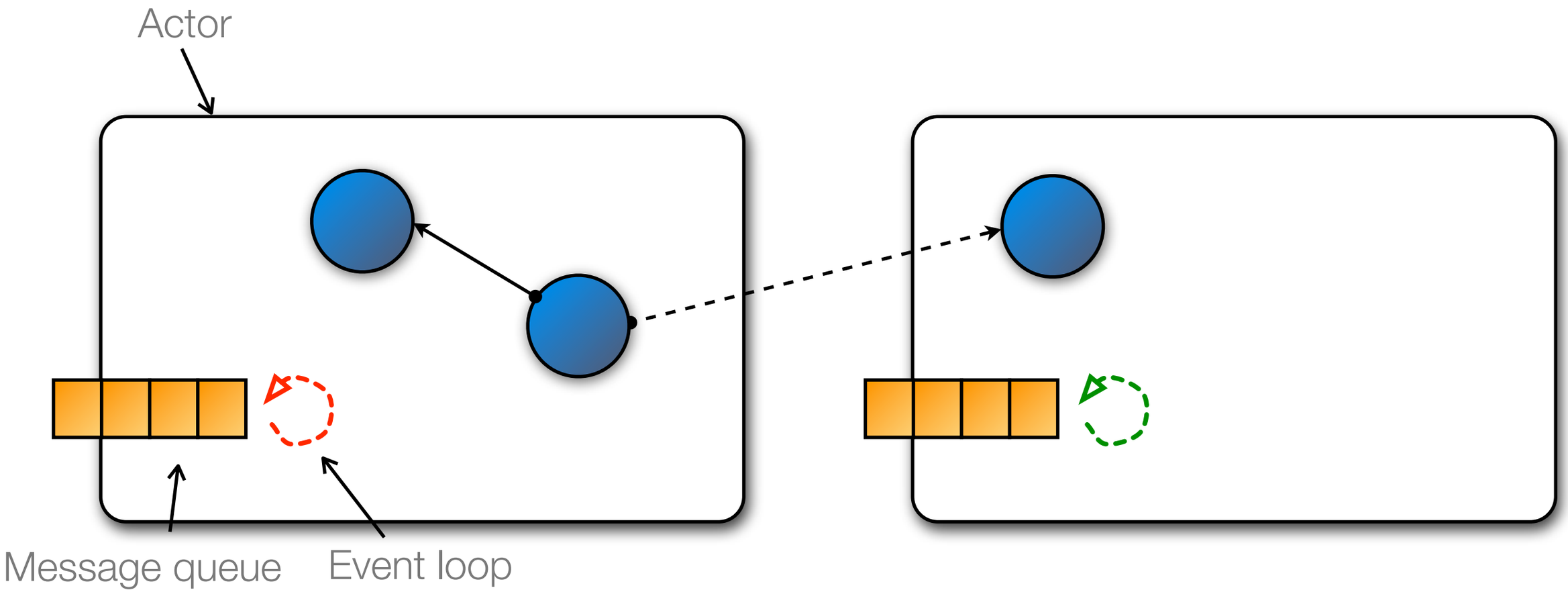
Evaluation

Implementation

Language Features



Event Loop Concurrency in AmbientTalk



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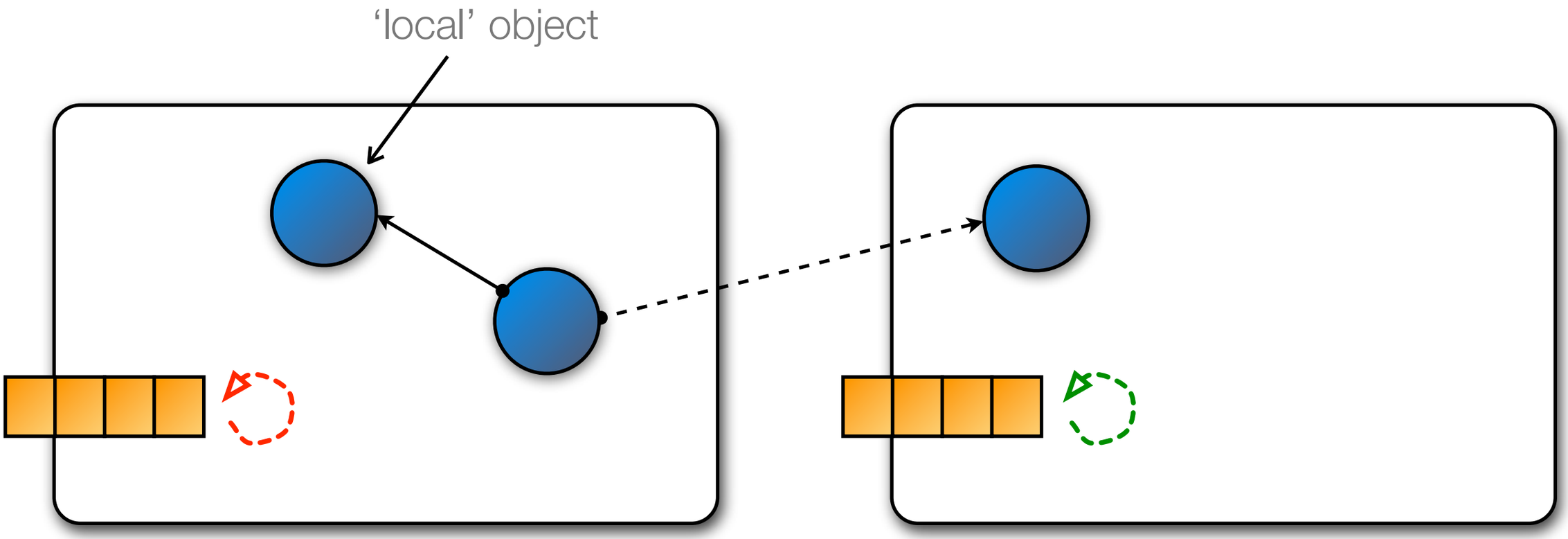

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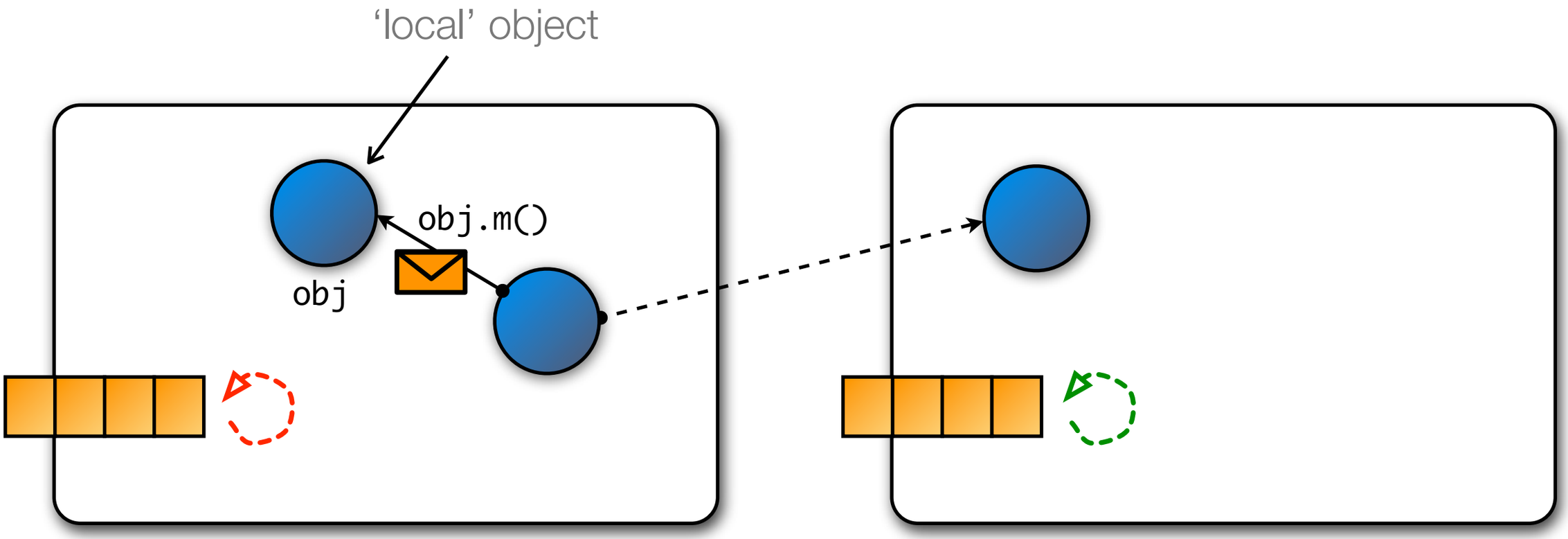

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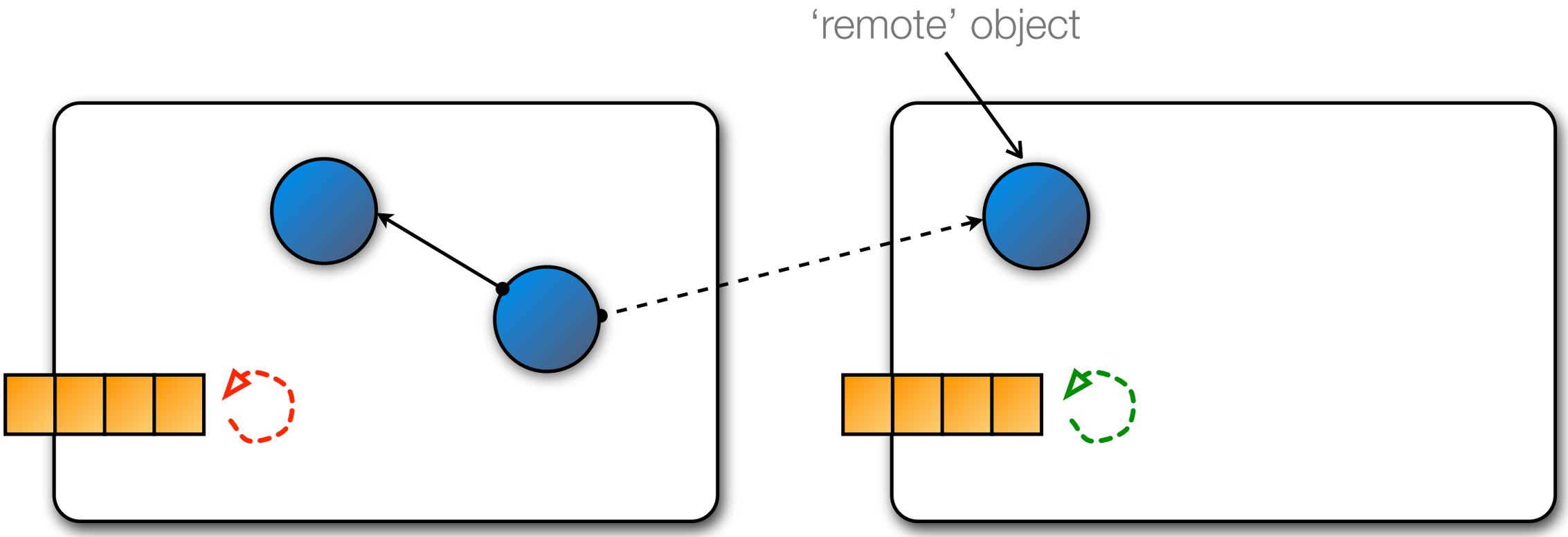

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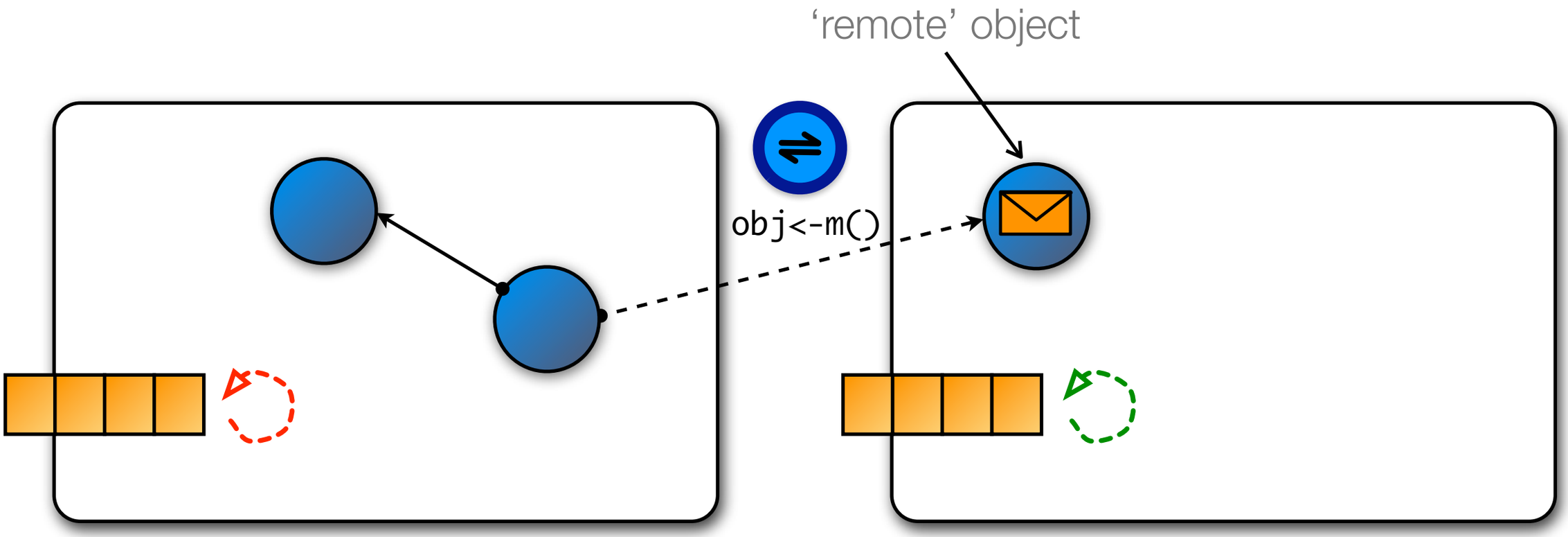

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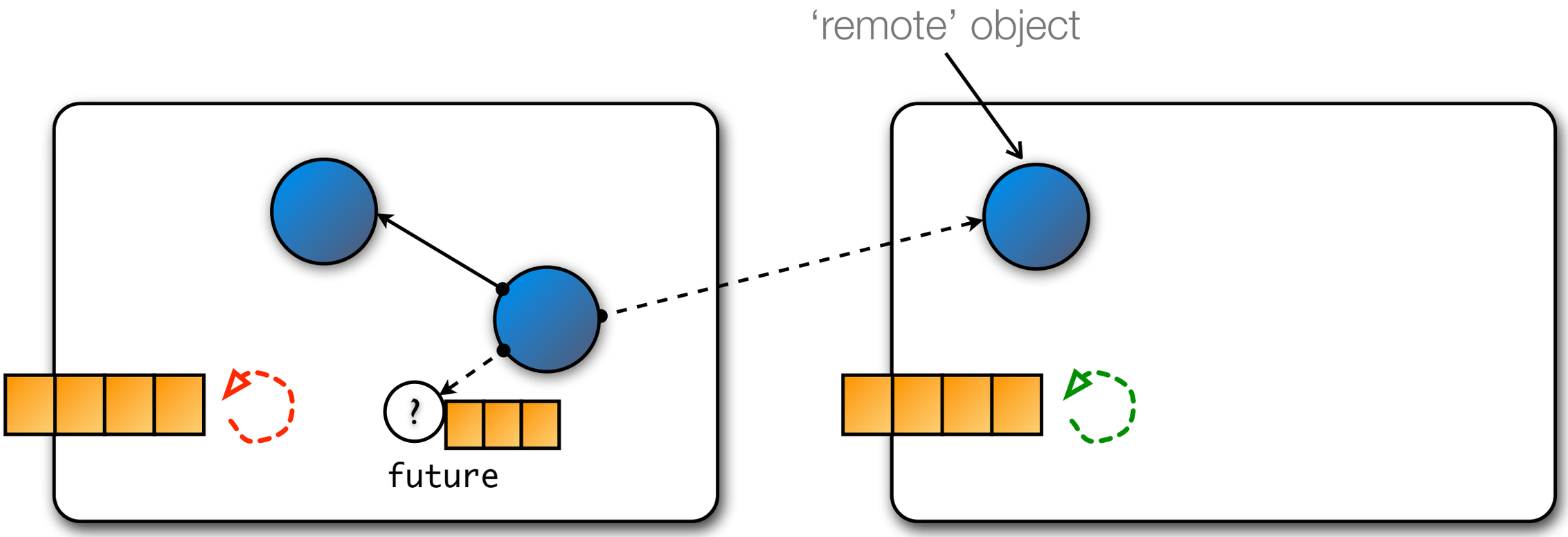

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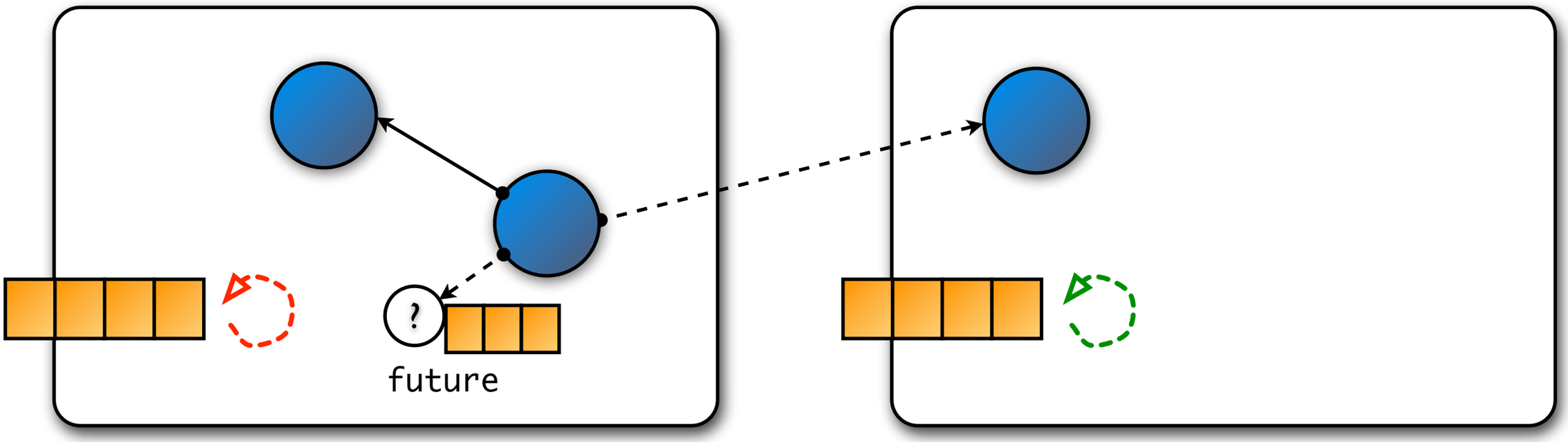
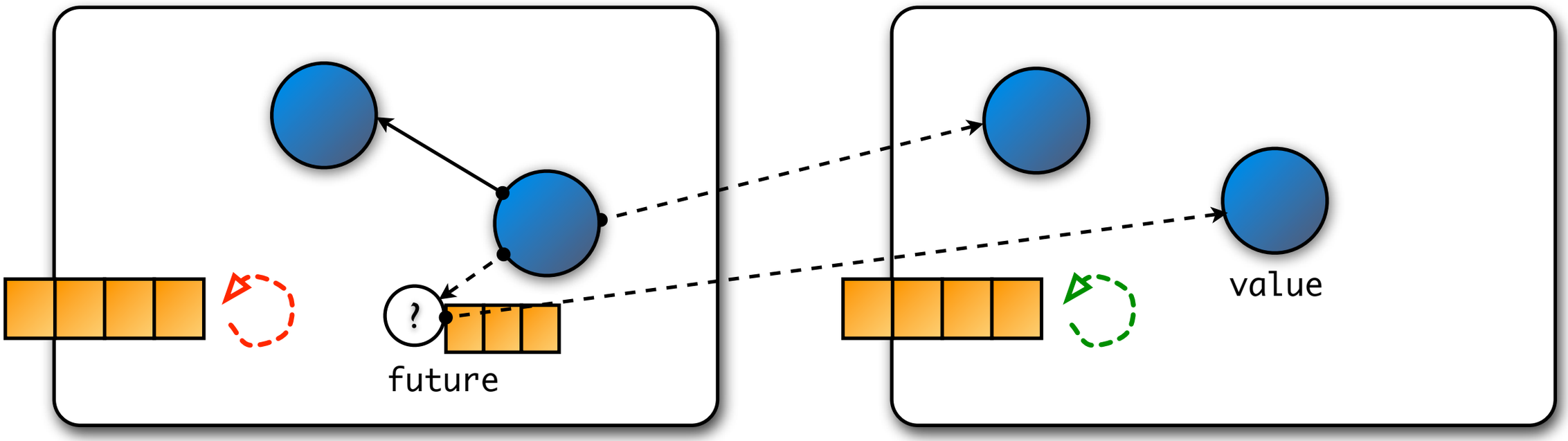


```
when: future becomes: { |value|
  // process reply
}
```

Event Loop Concurrency in AmbientTalk



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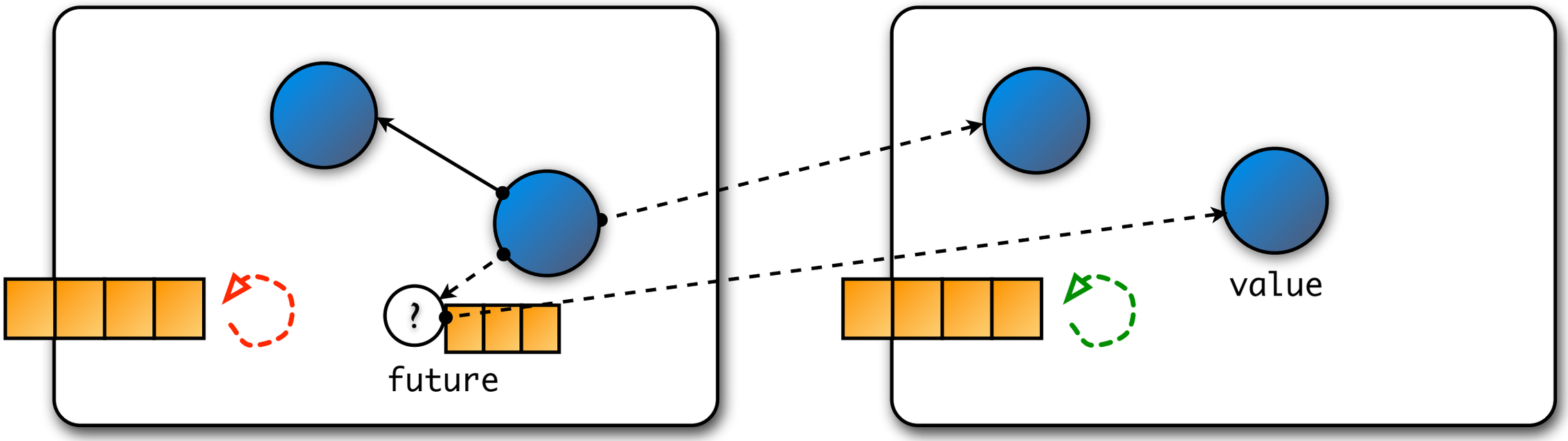

```
when: future becomes: { |value|
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}
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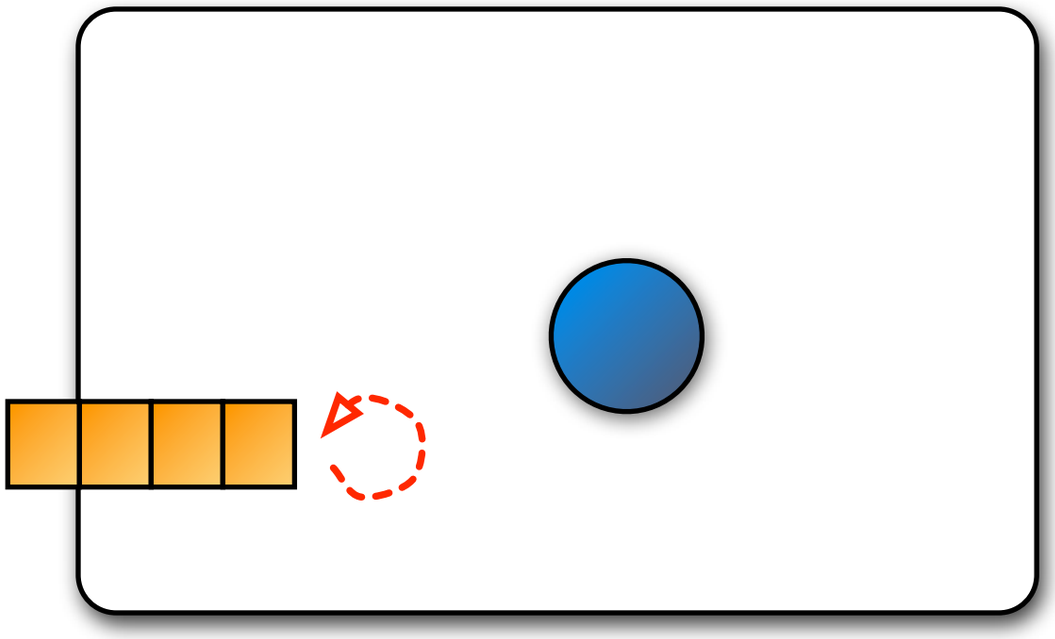
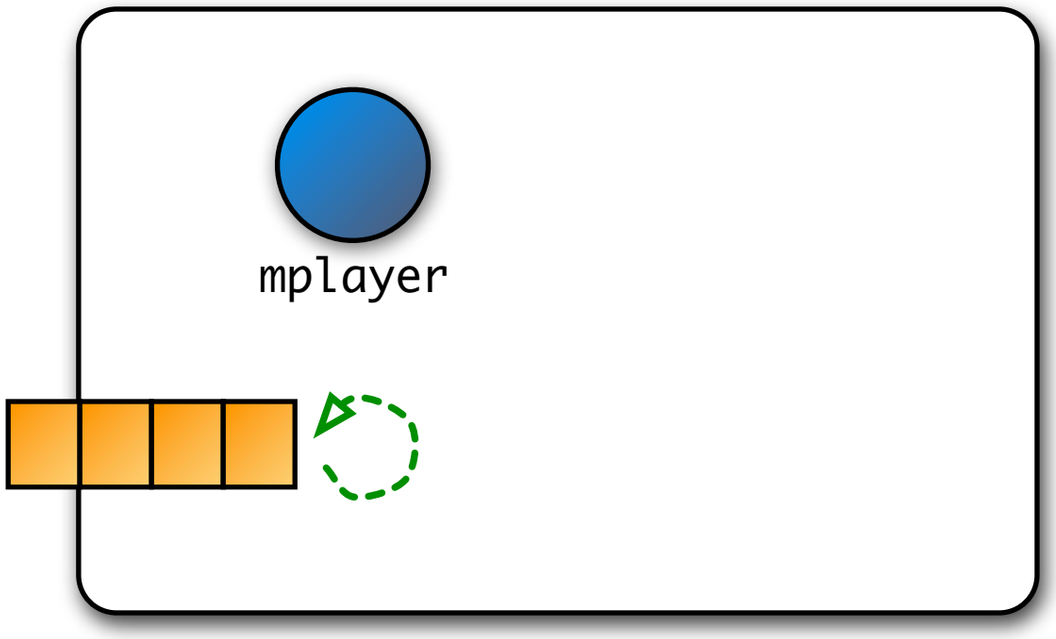
Actors cannot deadlock

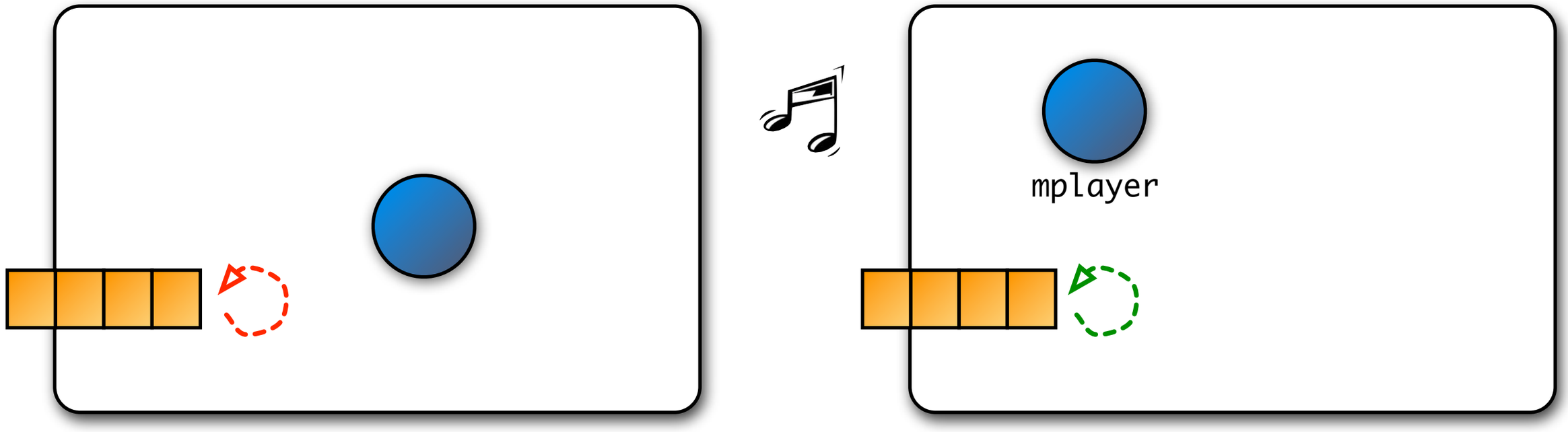
No race conditions on objects

Exporting & discovering objects





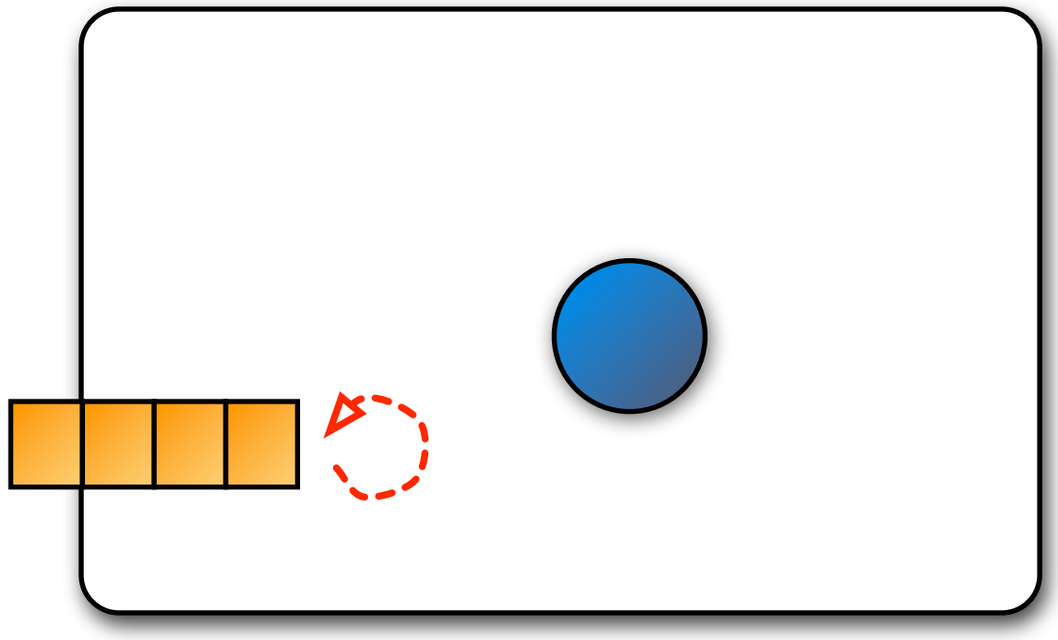
Exporting & discovering objects



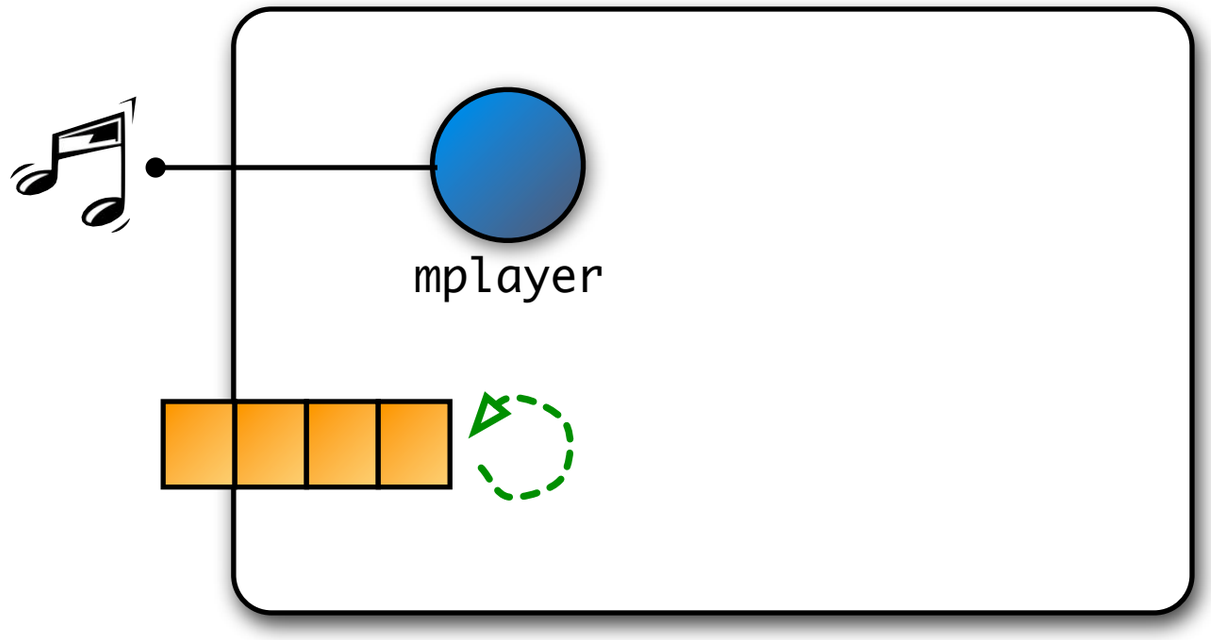
deftype MusicPlayer

deftype MusicPlayer

Exporting & discovering objects



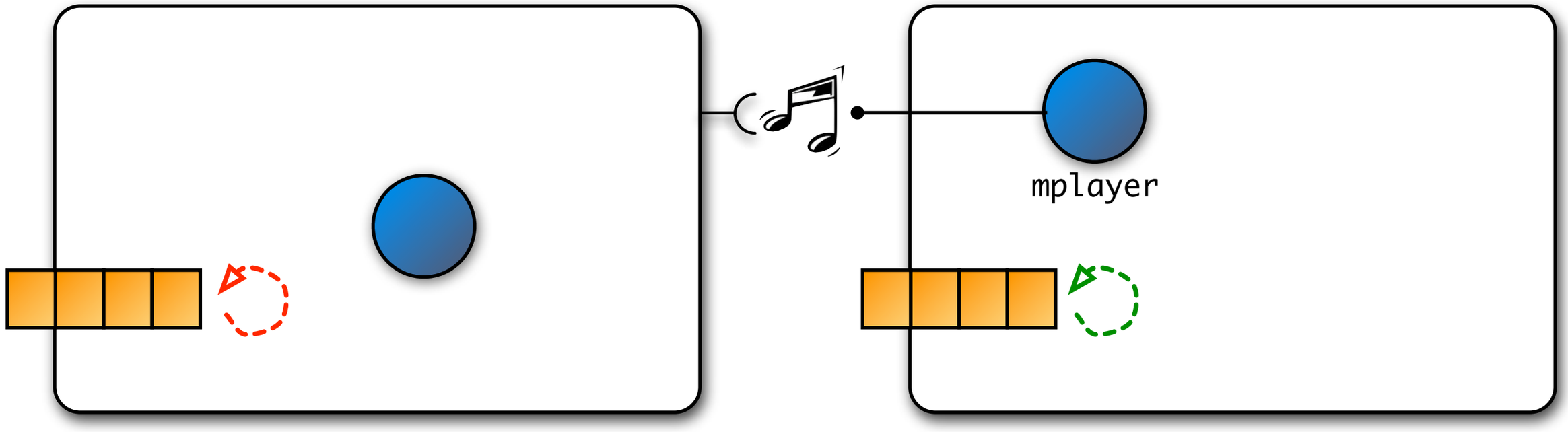
```
deftype MusicPlayer
```




```
deftype MusicPlayer

export: mplayer as: MusicPlayer
```

Exporting & discovering objects



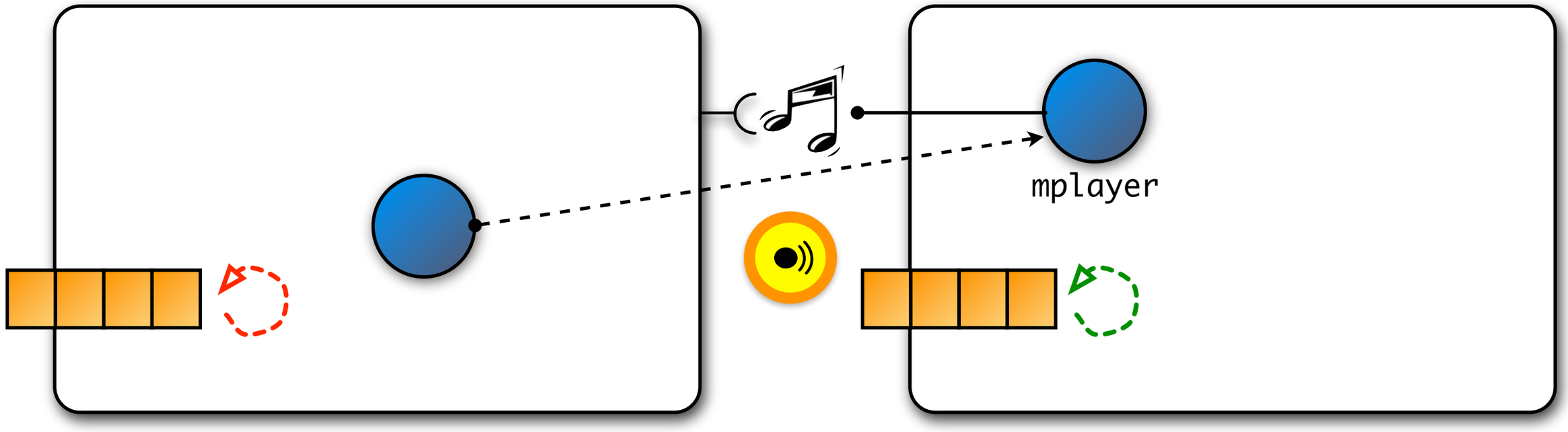

```
deftype MusicPlayer
```

```
deftype MusicPlayer

export: mplayer as: MusicPlayer
```

```
whenever: MusicPlayer discovered: { |mplayer|
  // open a session
}
```

Exporting & discovering objects

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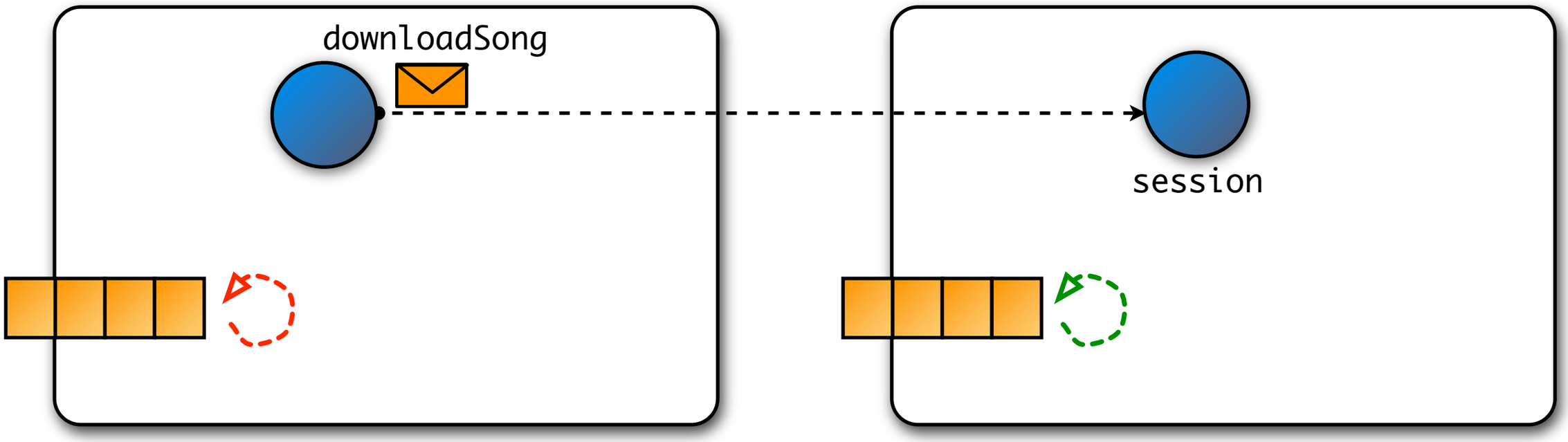
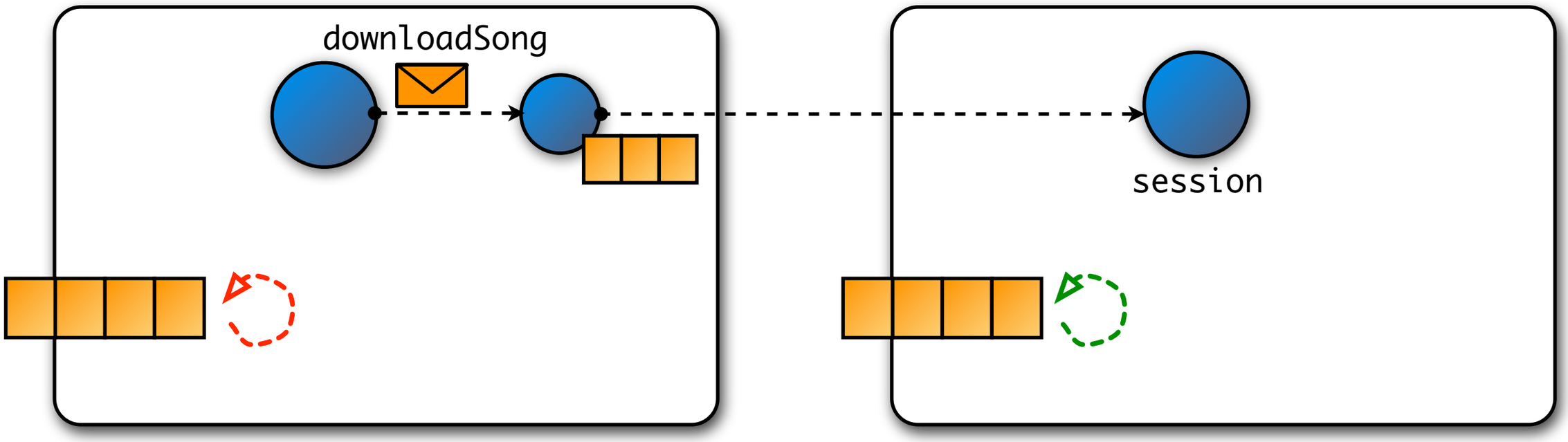
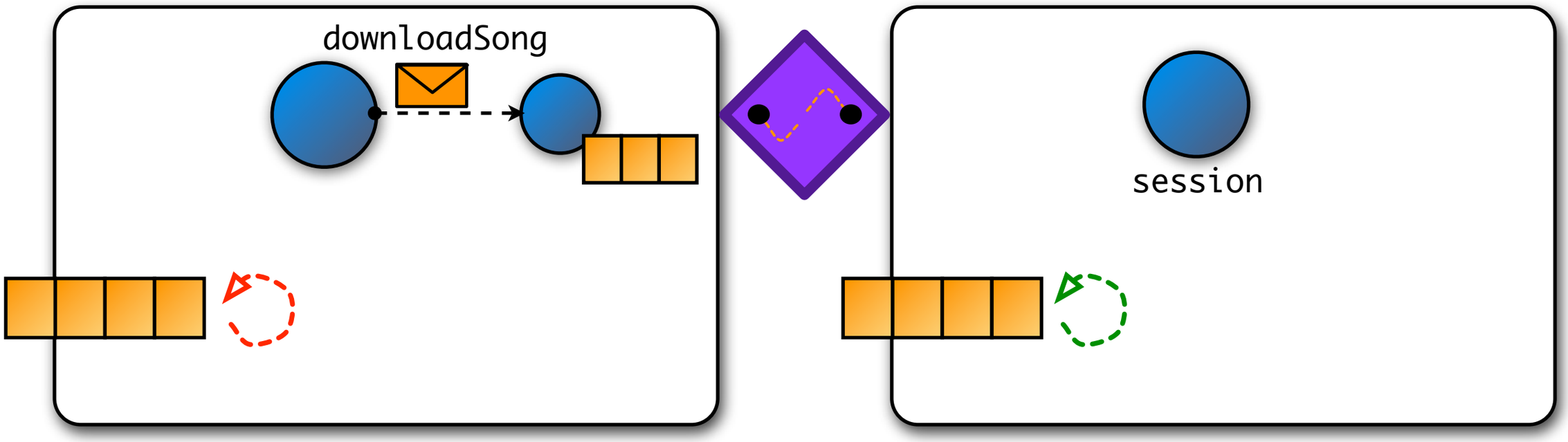
Far References



Far References



Far References



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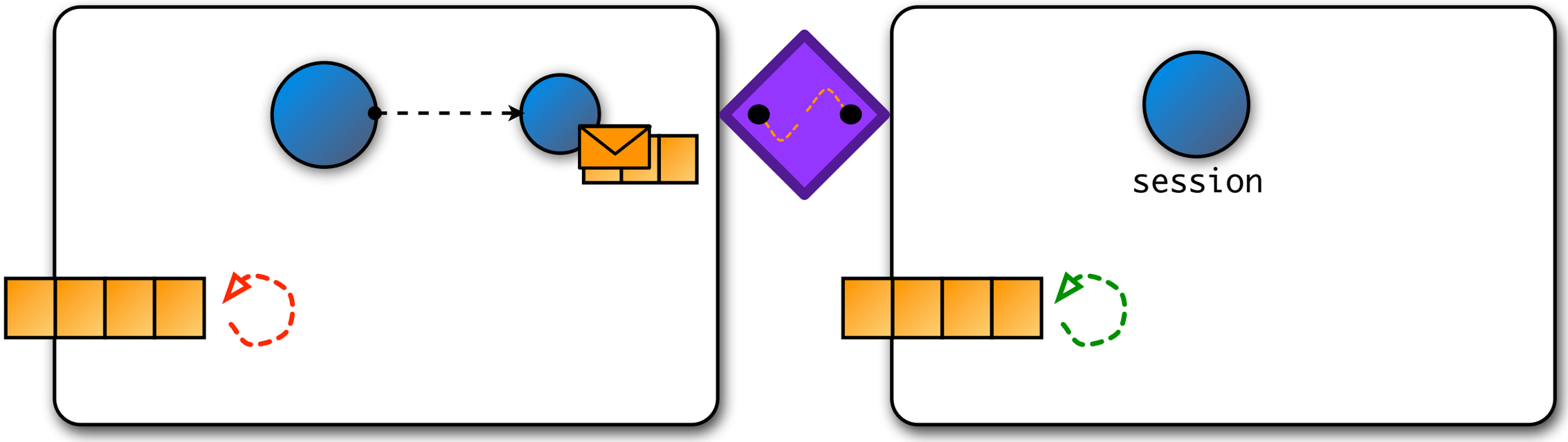
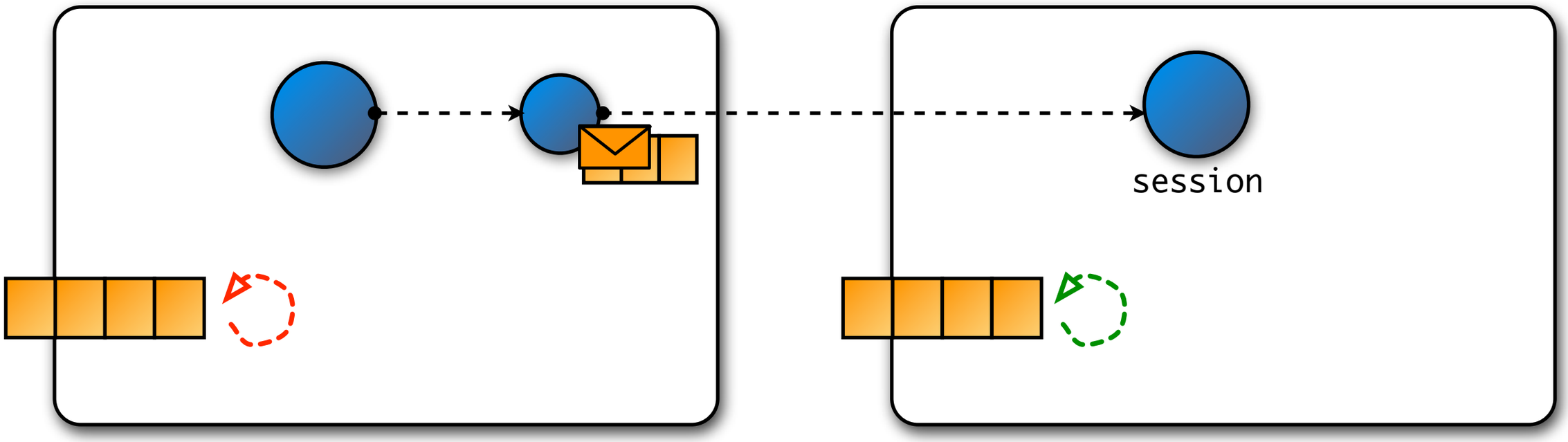
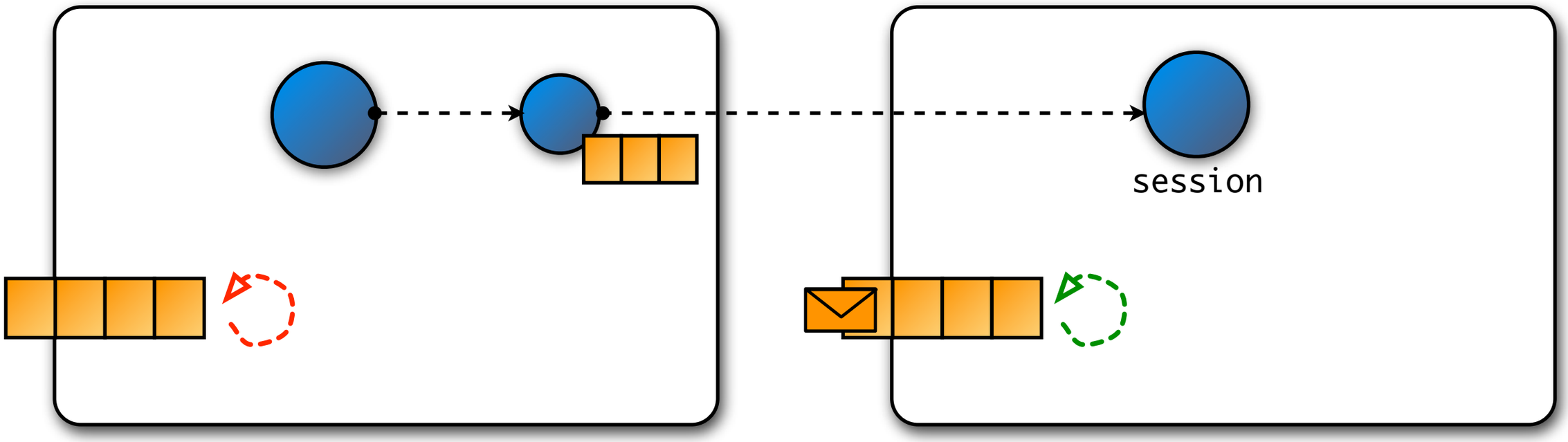


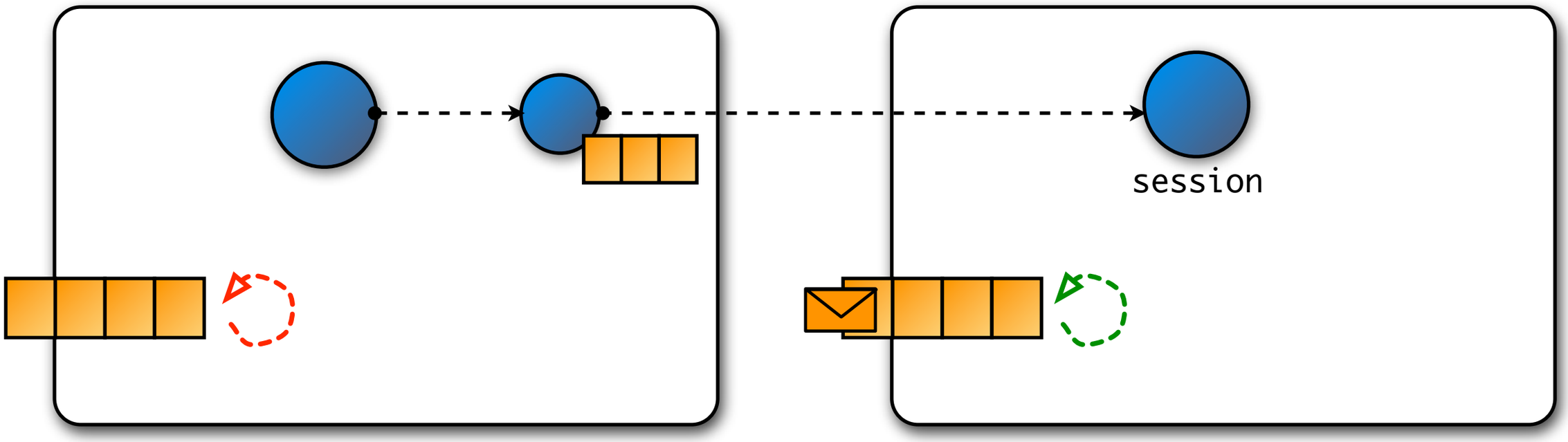
Far References



Far References



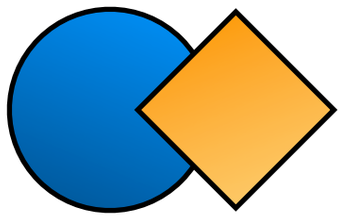
Far References




```
when: session<-downloadSong(s)@Due(timeout) becomes: { |ack|
  // continue exchange
} catch: TimeoutException using: { |e|
  // stop exchange
}
```

Roadmap

Motivation



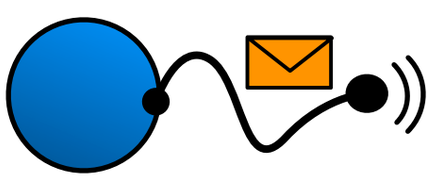
Object-event impedance mismatch

Coordination

Mobile ad hoc networks

Contribution

AMBIENTTALK



Ambient References

Validation

Evaluation

Implementation

Ambient References

Motivation

Contribution

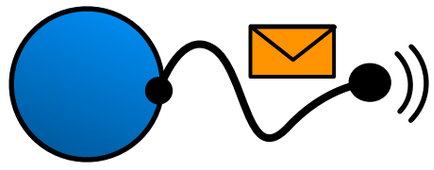
Validation

Object-event impedance mismatch

Coordination

Evaluation

Mobile ad hoc networks

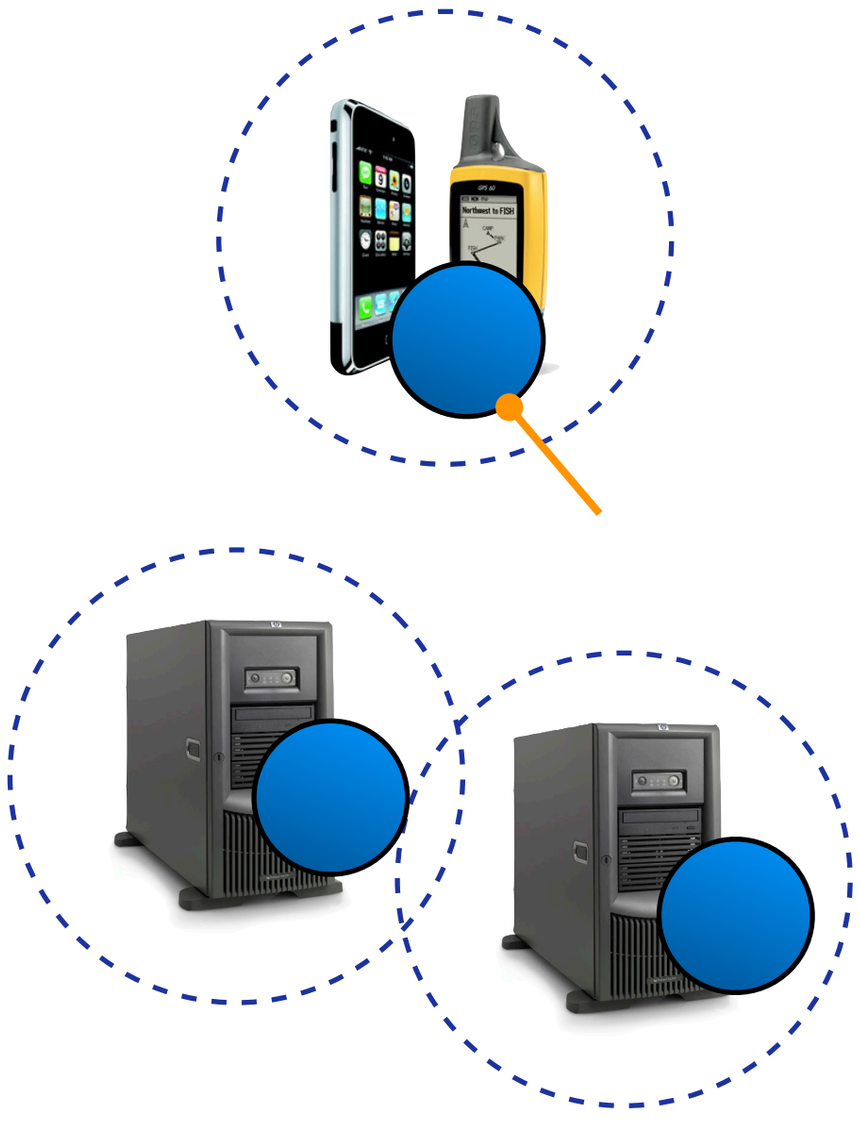


Ambient References

Implementation

Motivation

Second-class communication patterns



Roaming

Motivation

Second-class communication patterns

Roaming

Motivation

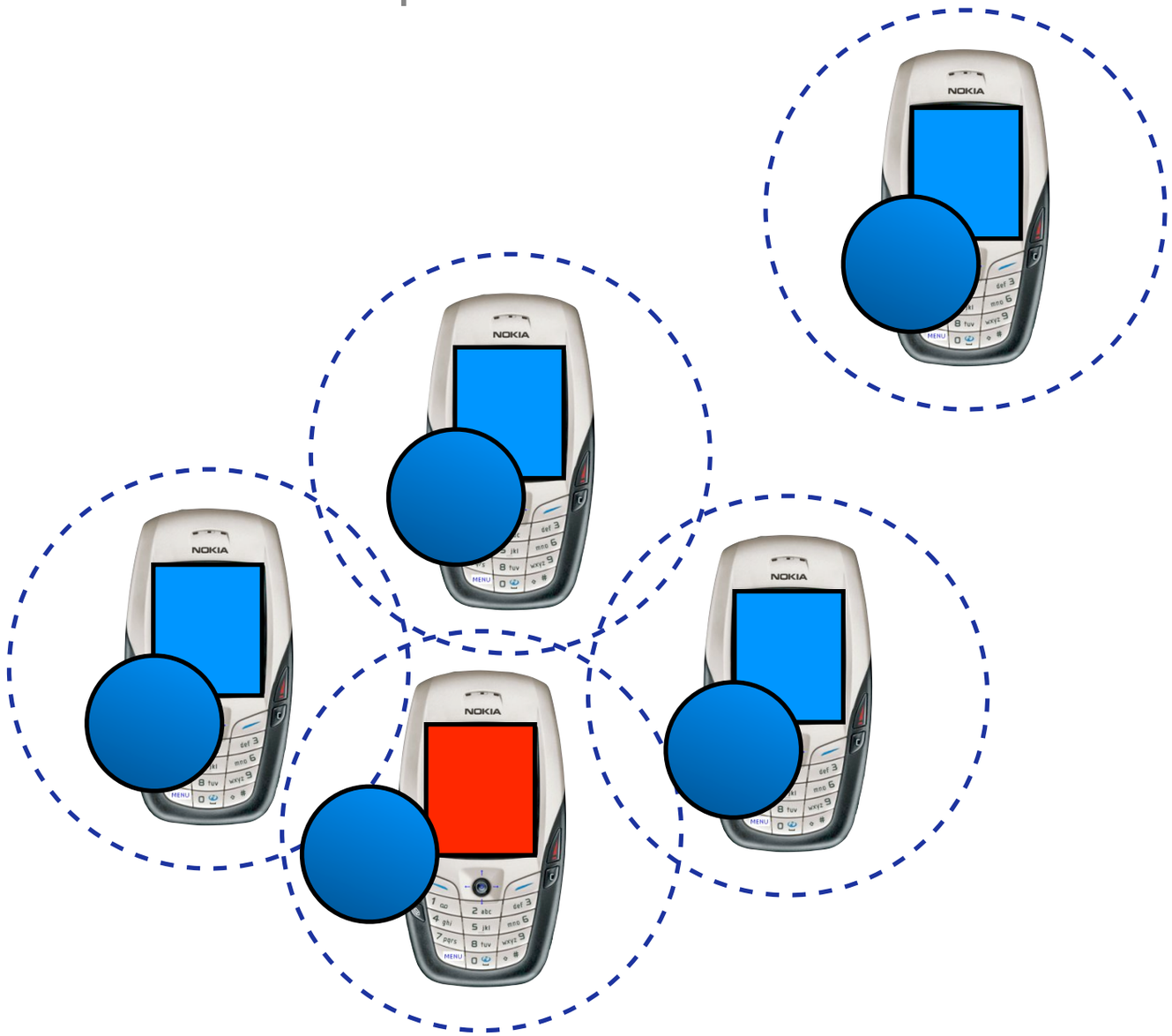
Second-class communication patterns

Roaming

Motivation

Second-class communication patterns

Roaming

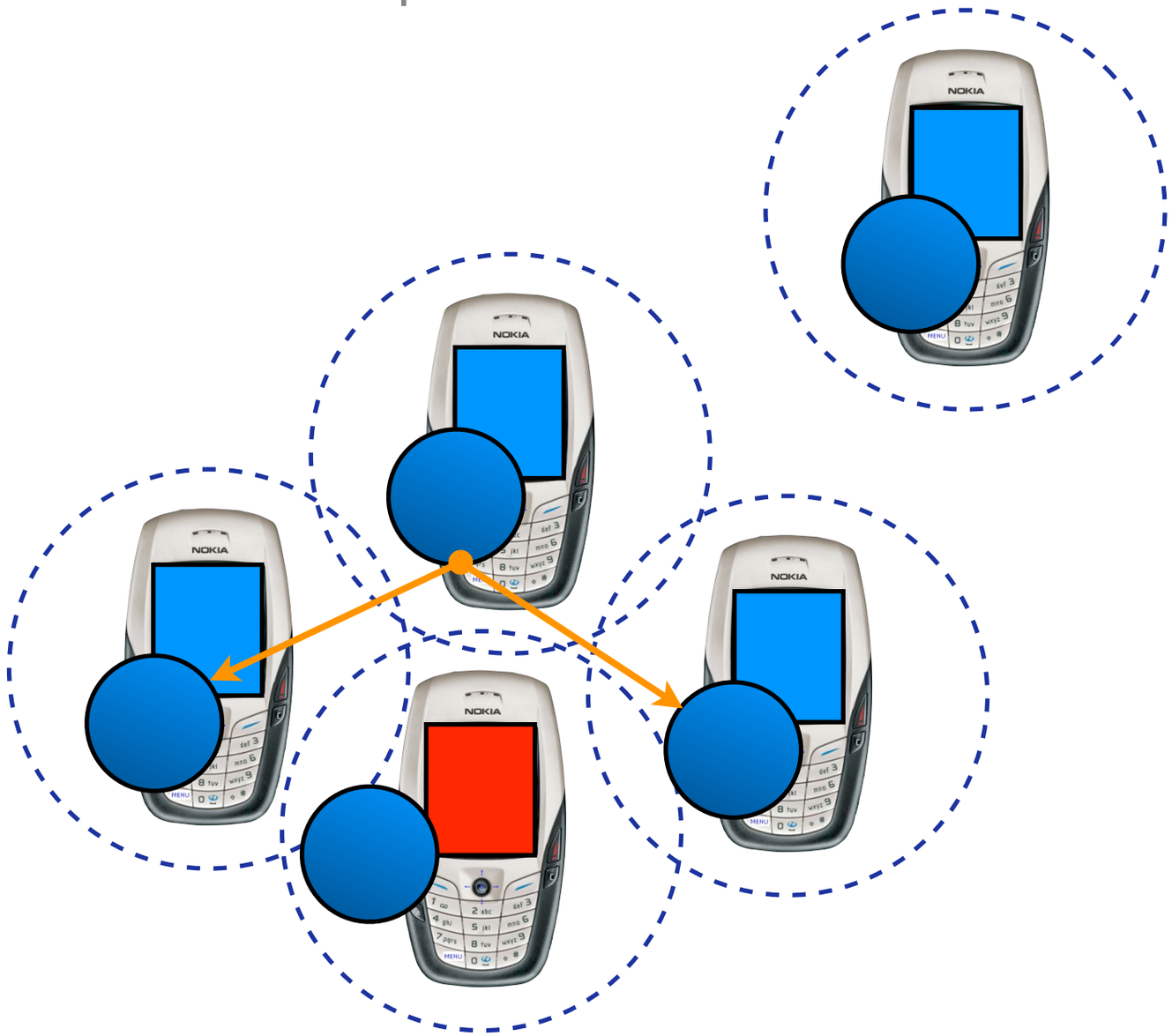


One-to-many communication

Motivation

Second-class communication patterns

Roaming

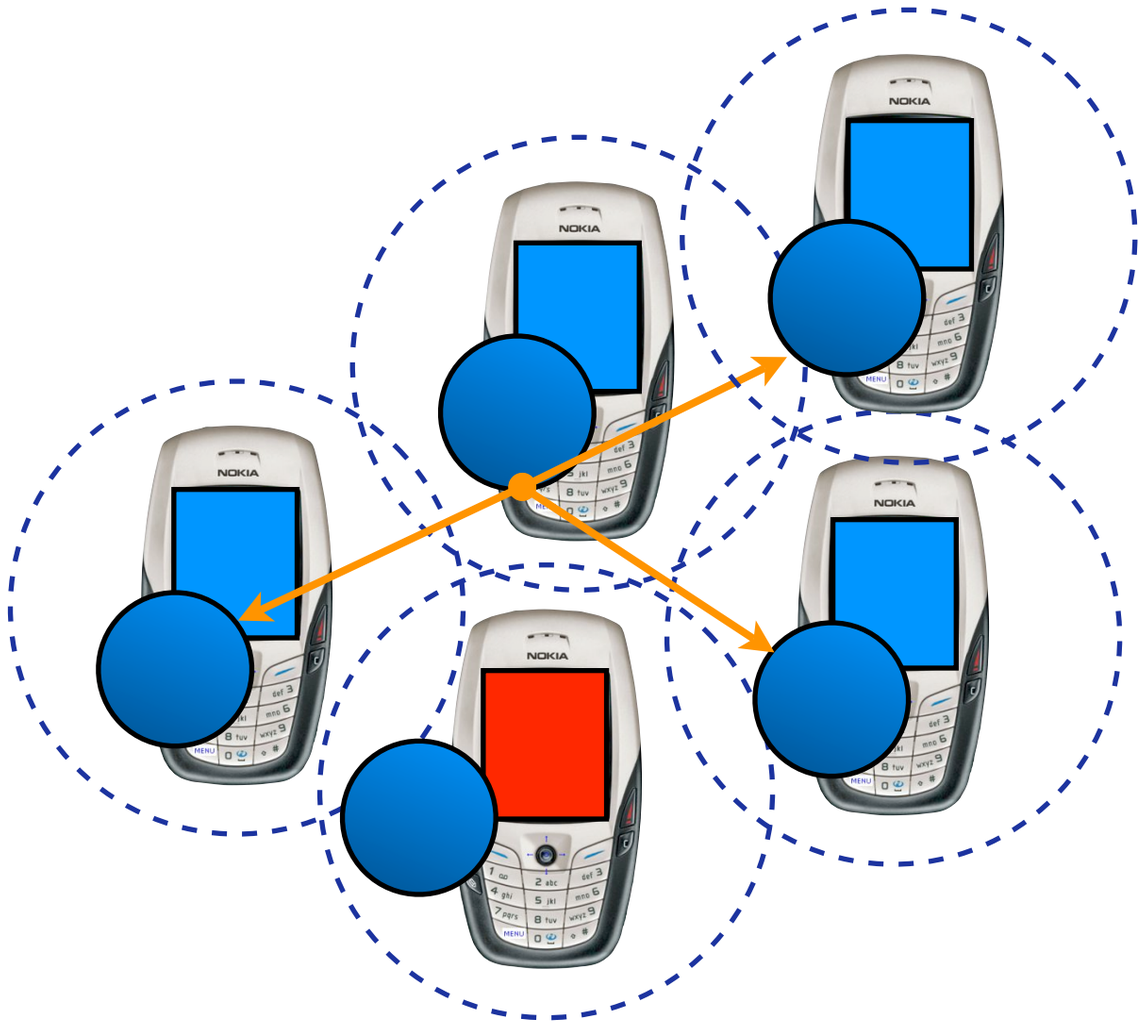


One-to-many communication

Motivation

Second-class communication patterns

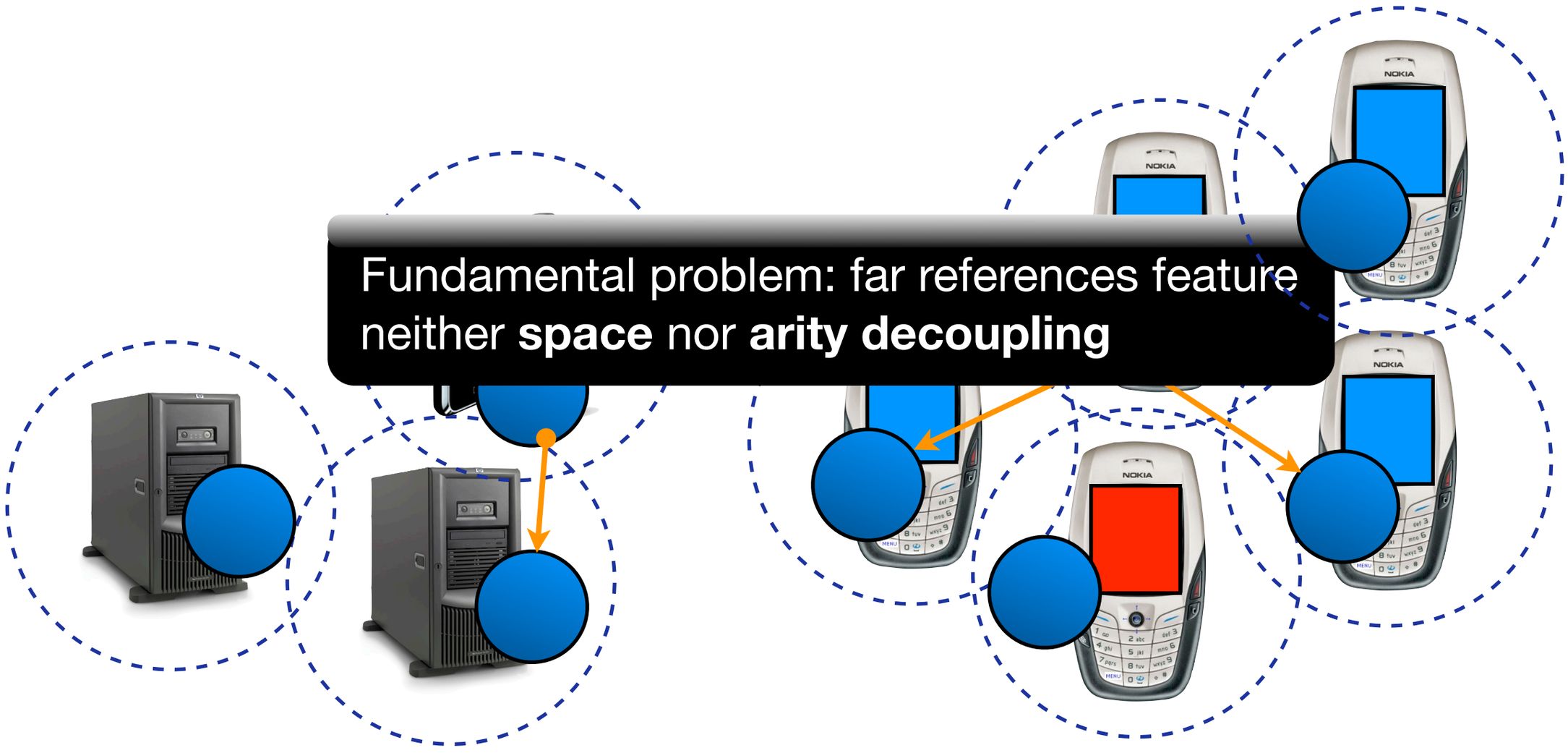
Roaming



One-to-many communication

Motivation

Second-class communication patterns

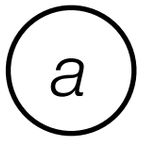


Roaming

One-to-many communication

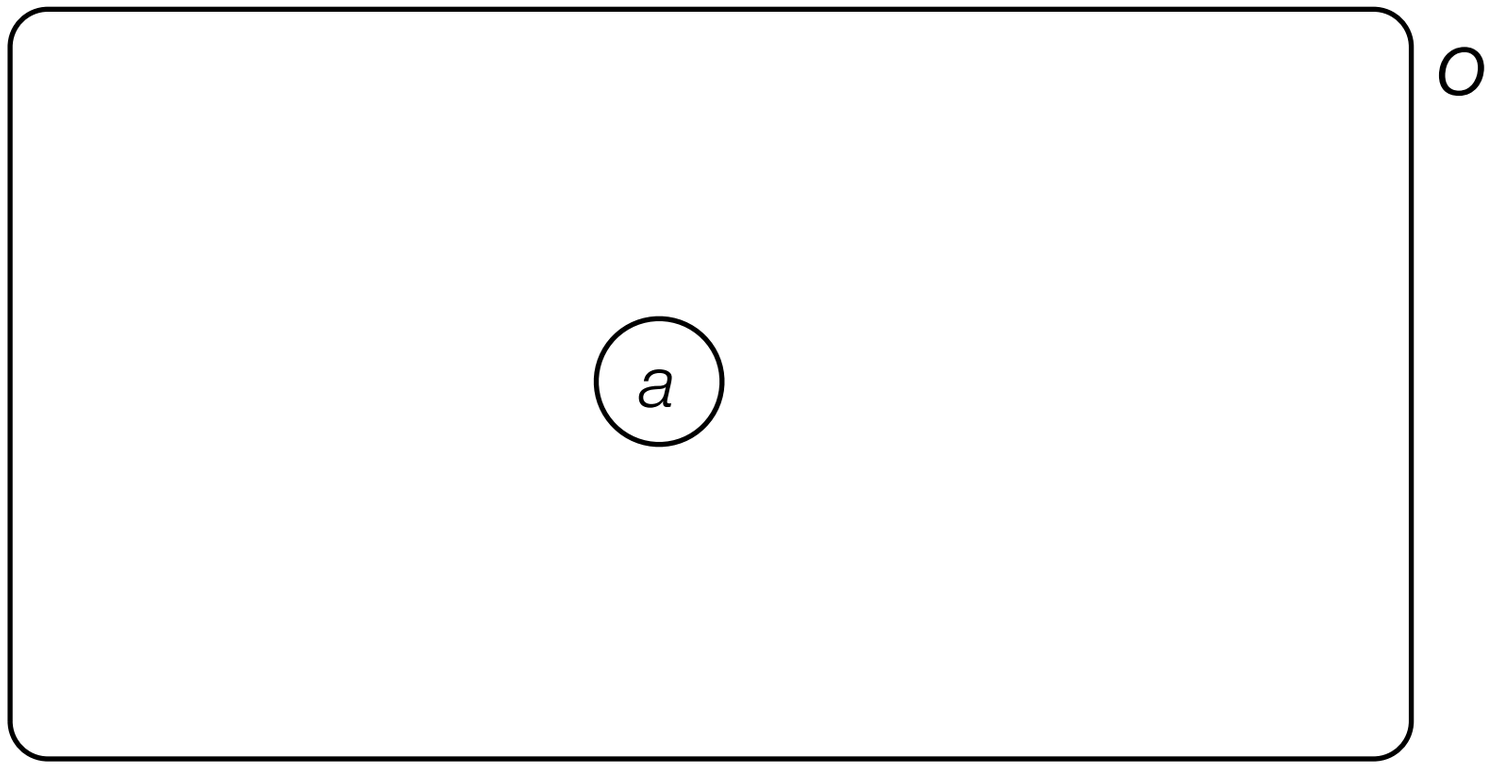
Abstractly spoken

Ambient reference $a = \langle f, M \rangle$



Abstractly spoken

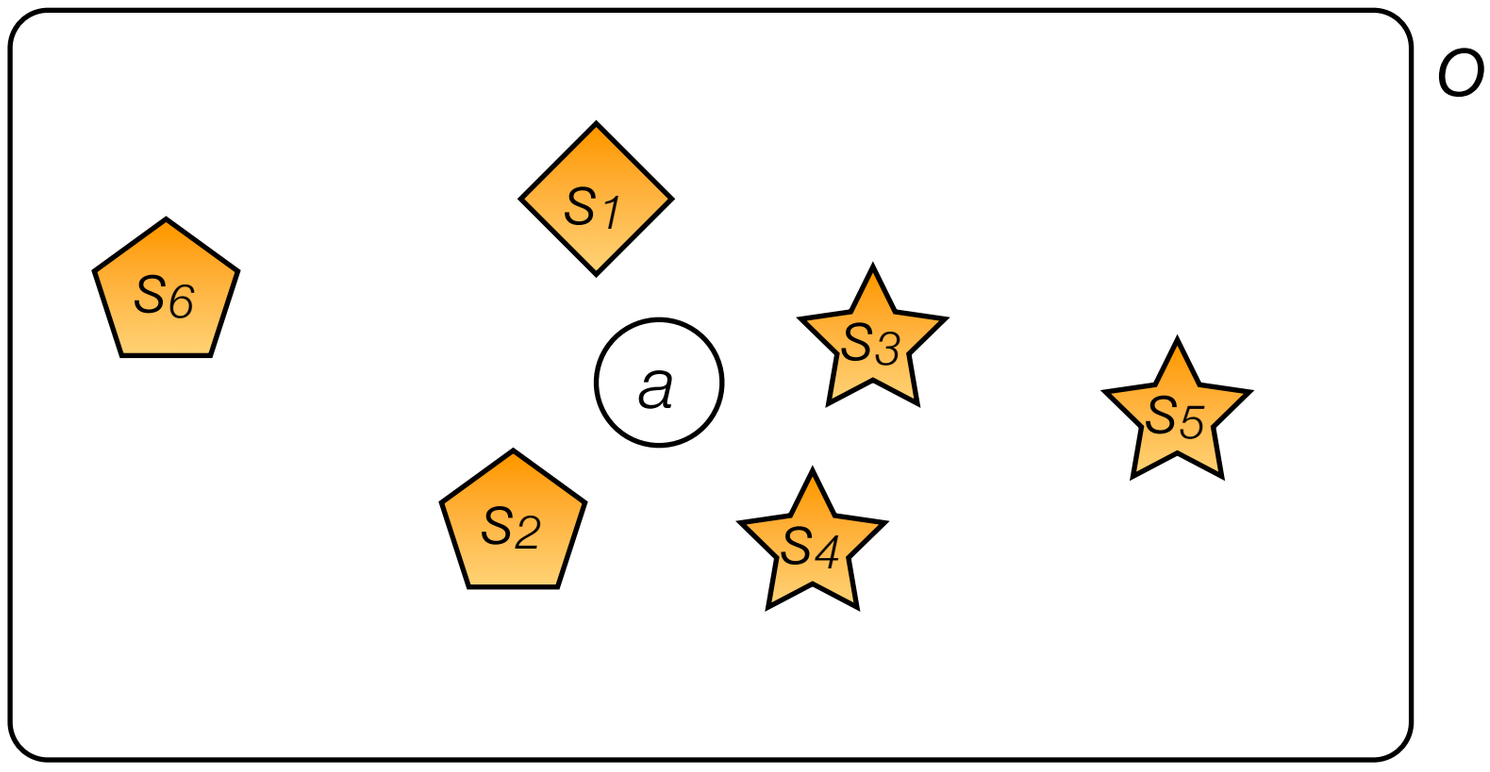
Ambient reference $a = \langle f, M \rangle$



Universe *O*

Abstractly spoken

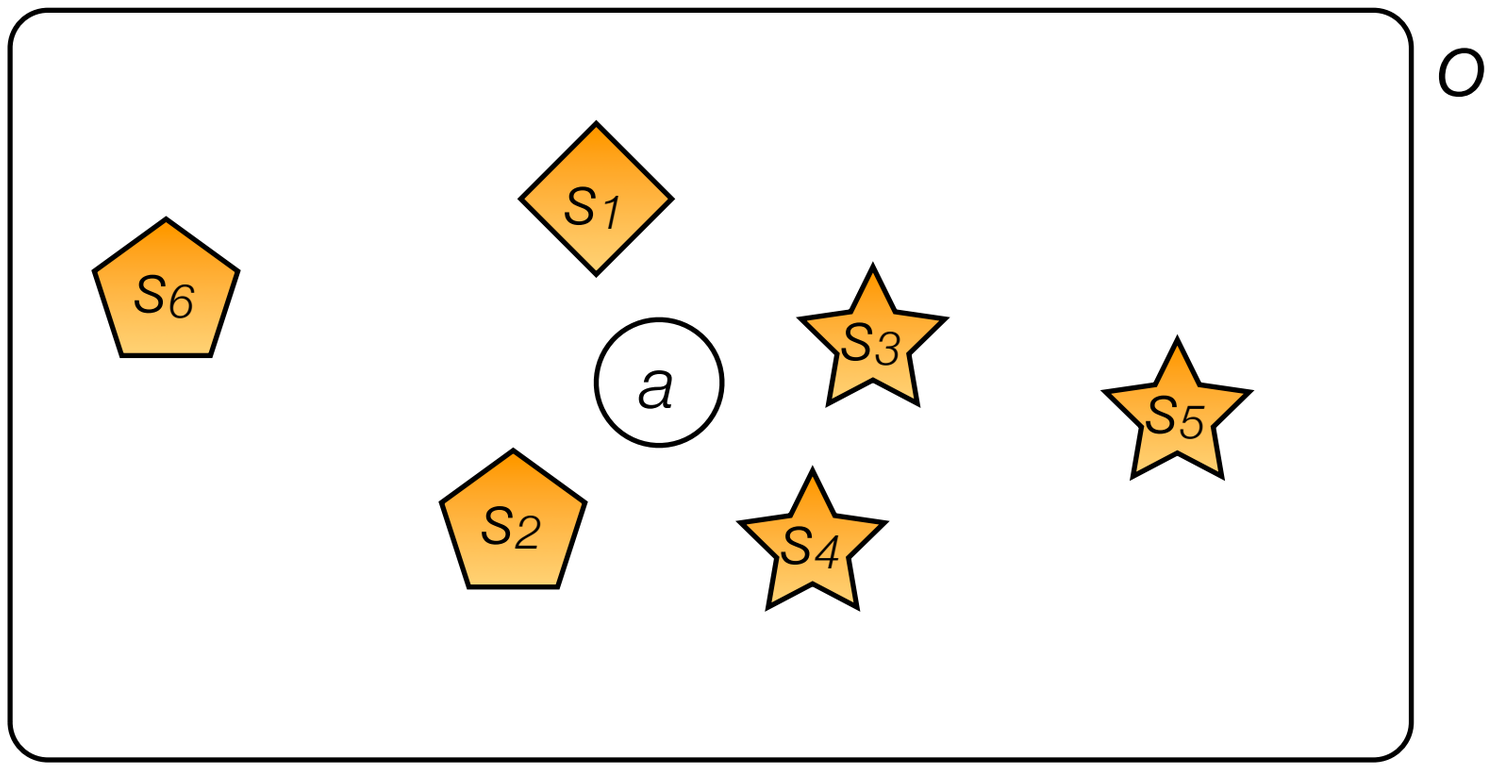
Ambient reference $a = \langle f, M \rangle$



Universe *O*

Abstractly spoken

Ambient reference $a = \langle f, M \rangle$ $f_a(s) = s \equiv$ 



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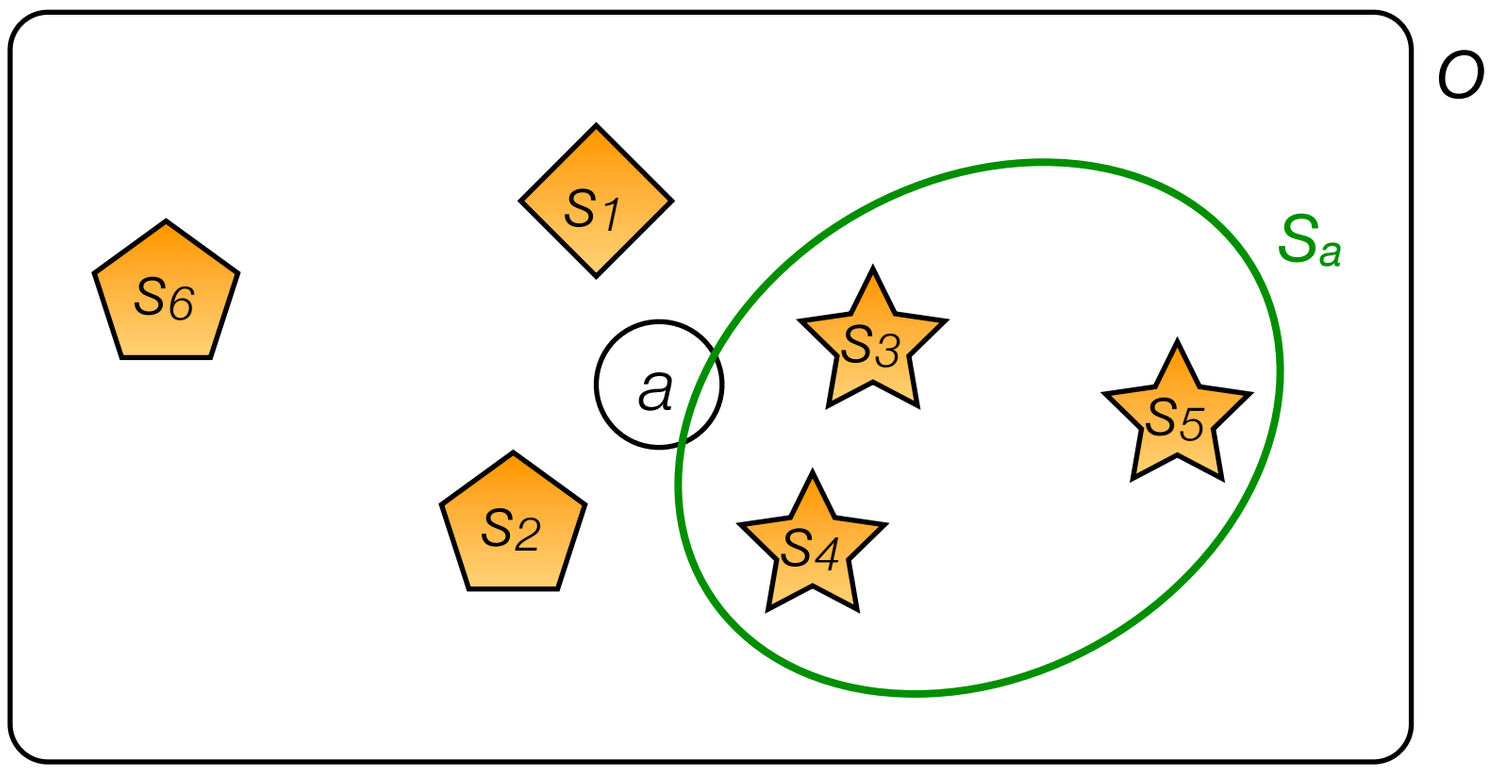
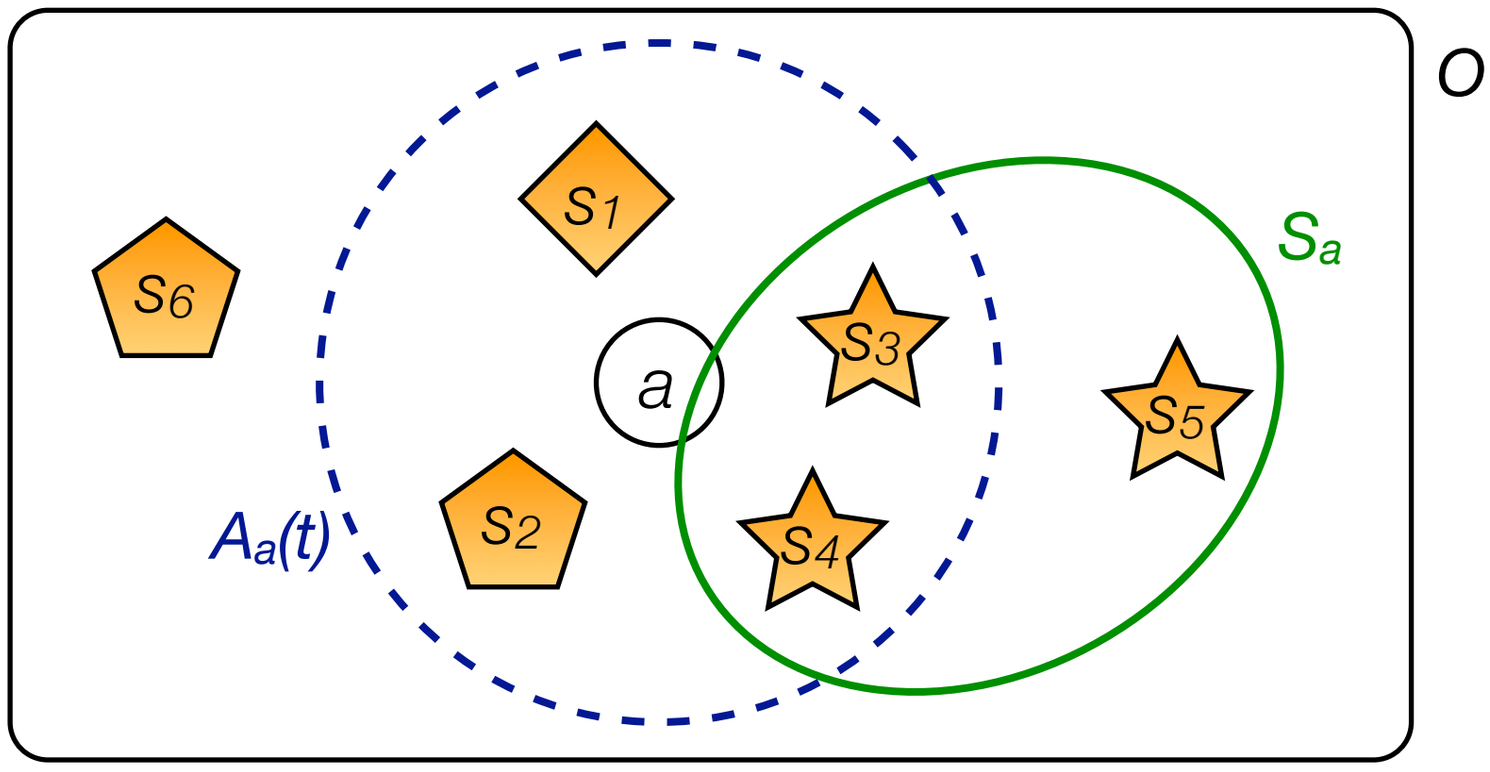


Universe O

Scope $S_a = \{ s \in O \mid f_a(s) \}$

Abstractly spoken

Ambient reference $a = \langle f, M \rangle$ $f_a(s) = s \equiv$ ★



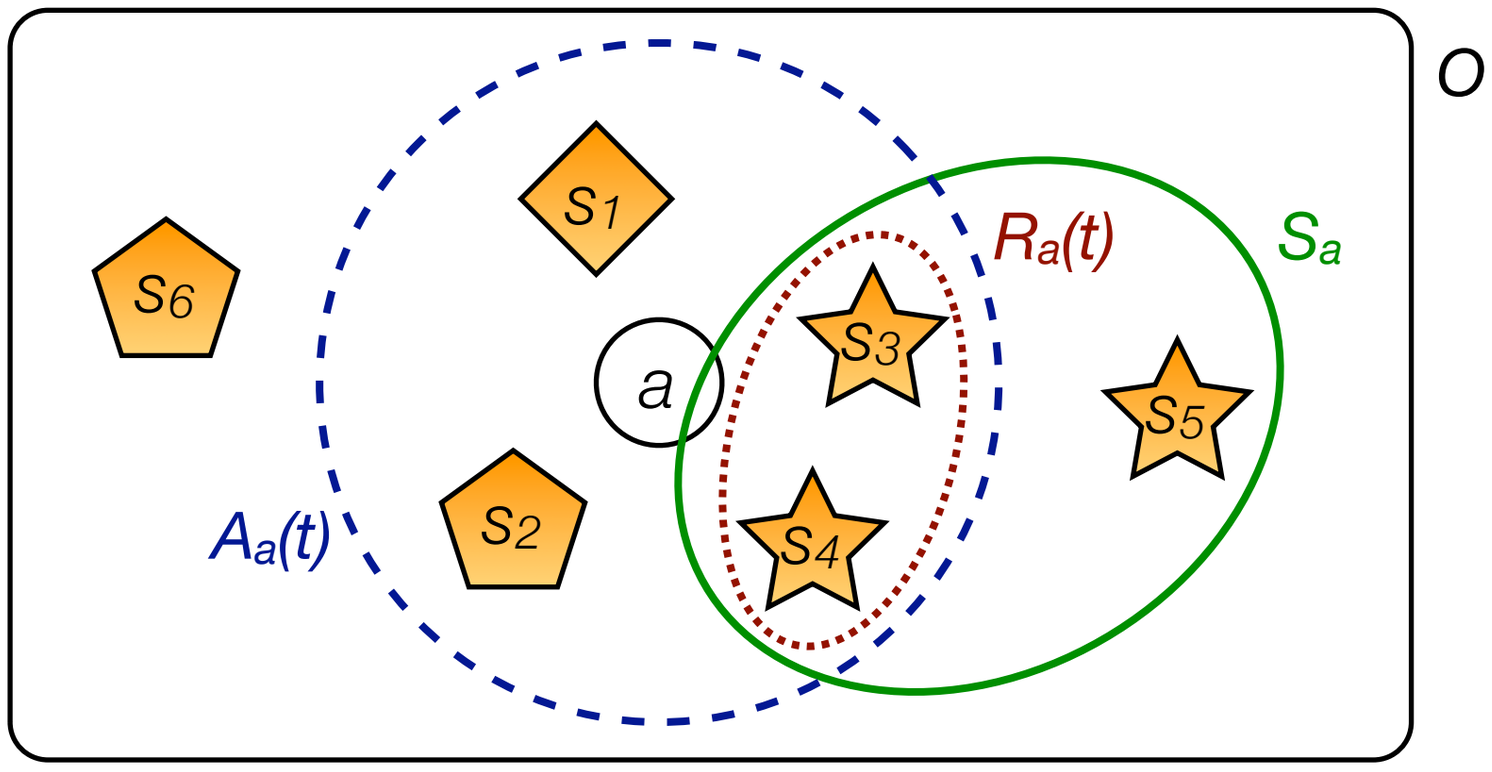
Universe O

Scope $S_a = \{ s \in O \mid f_a(s) \}$

Range $A_a(t)$ = all objects in communication range at time t

Abstractly spoken

Ambient reference $a = \langle f, M \rangle$ $f_a(s) = s \equiv$ ★



Universe O

Scope $S_a = \{ s \in O \mid f_a(s) \}$

Range $A_a(t)$ = all objects in communication range at time t

Reach $R_a(t) = S_a \cap A_a(t)$

Concretely spoken


```
def players := ambient: Player where: { |p| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

Concretely spoken

Scope

```
def players := ambient: Player where: { |pl| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

Concretely spoken

Type tags

```
deftype Player;
```

Scope

```
def players := ambient: Player where: { |pl| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

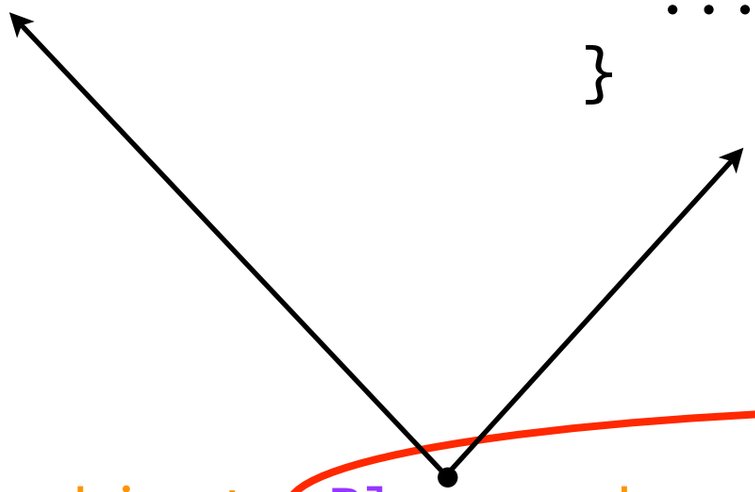
Concretely spoken

Type tags

```
deftype Player;
```

Protocols

```
def Player := protocol: {
  def askToVote(question);
  ...
}
```



Scope

```
def players := ambient: Player where: { |pl| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

Concretely spoken


```
def players := ambient: Player where: { |pl| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

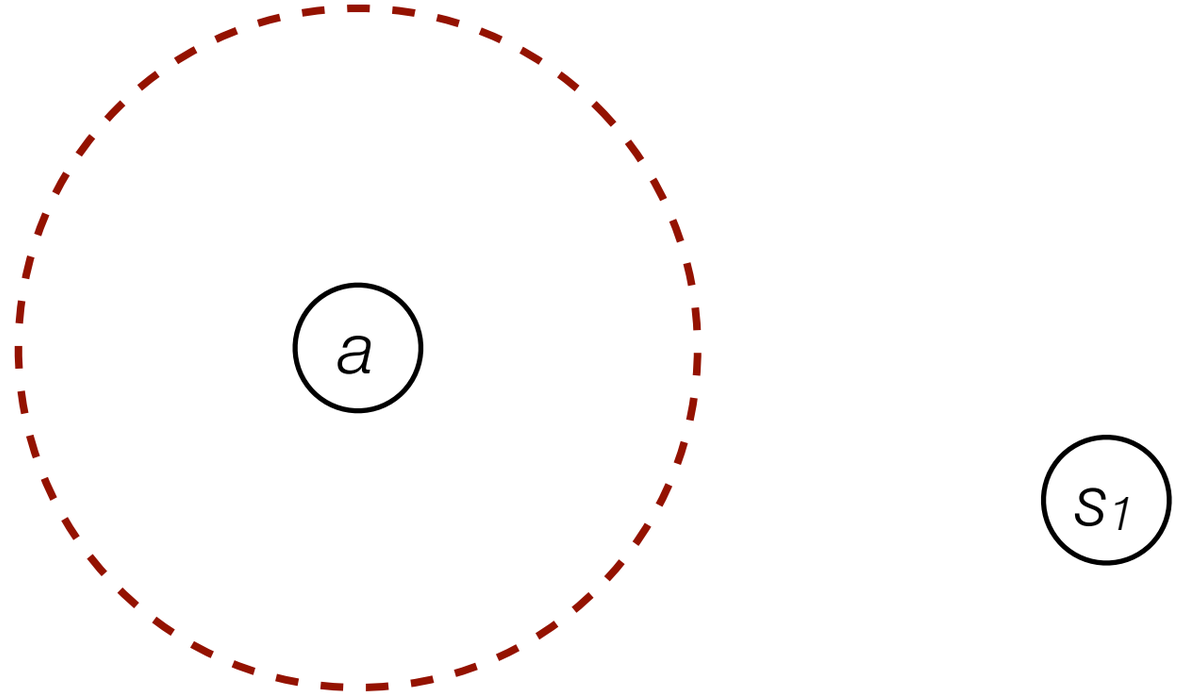
Eventual reference

Concretely spoken


```
def players := ambient: Player where: { |p| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
```

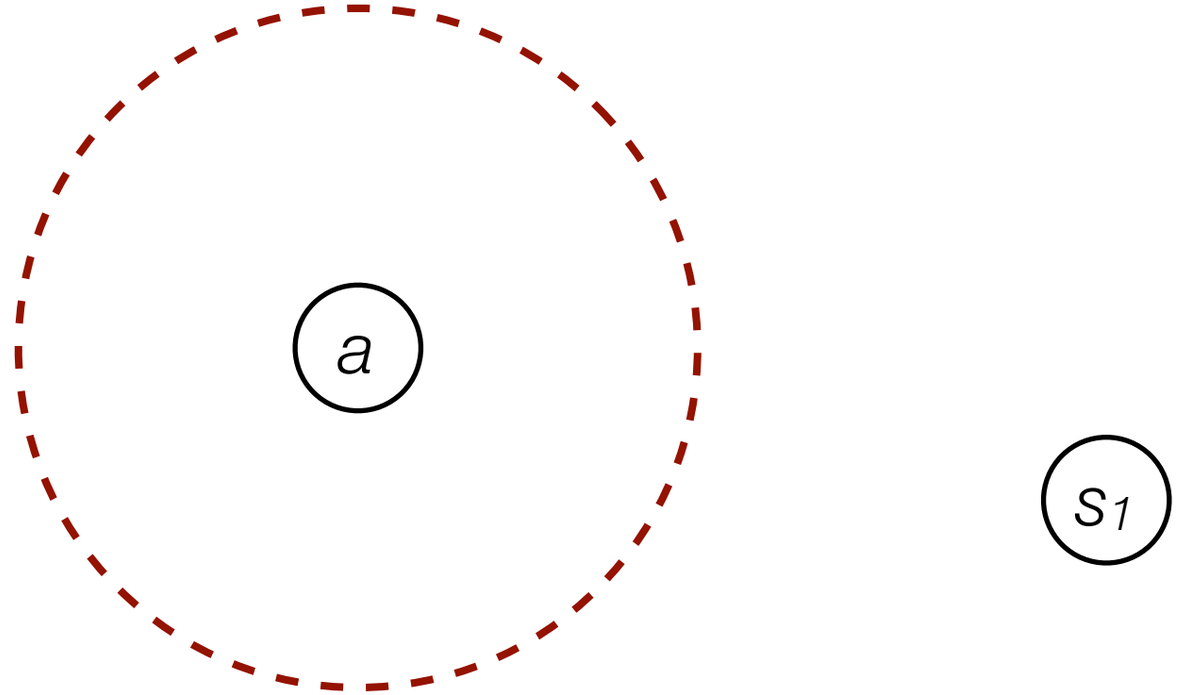
Delivery policies

Example: Location Tracker




```
def ap := ambient: LocationService;
def updateLocation(newLoc) {
   ap<-submitLocation(id,newLoc)@[One,Instant,Oneway];
}
```

Example: Location Tracker

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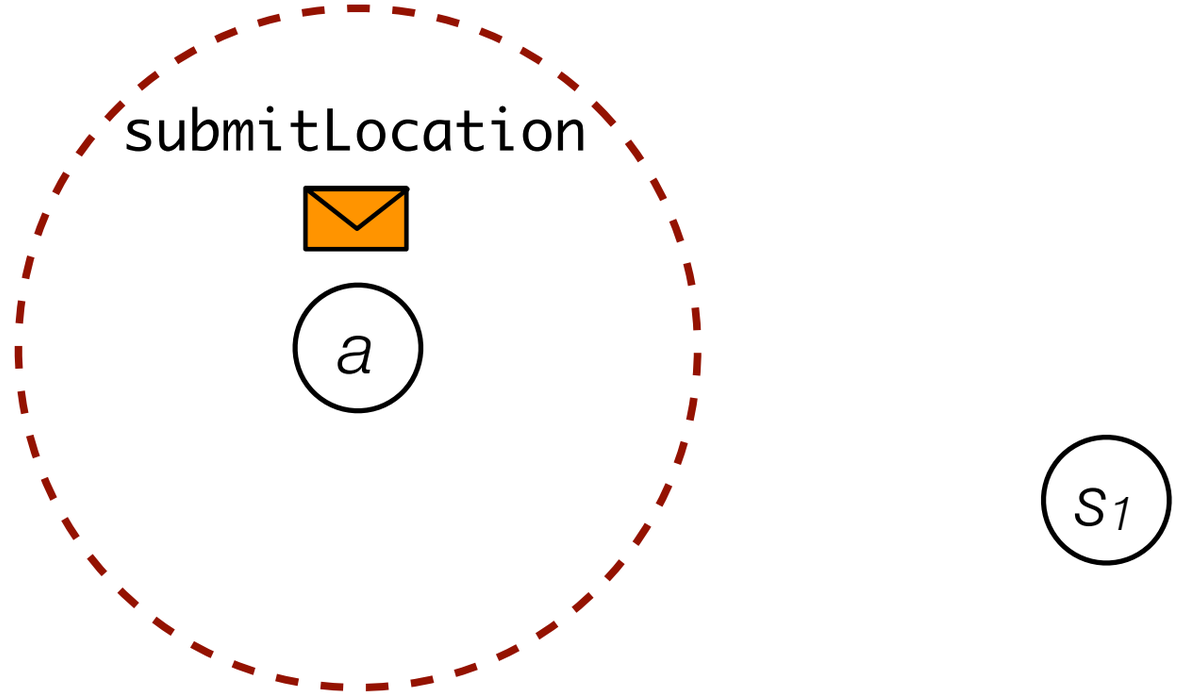
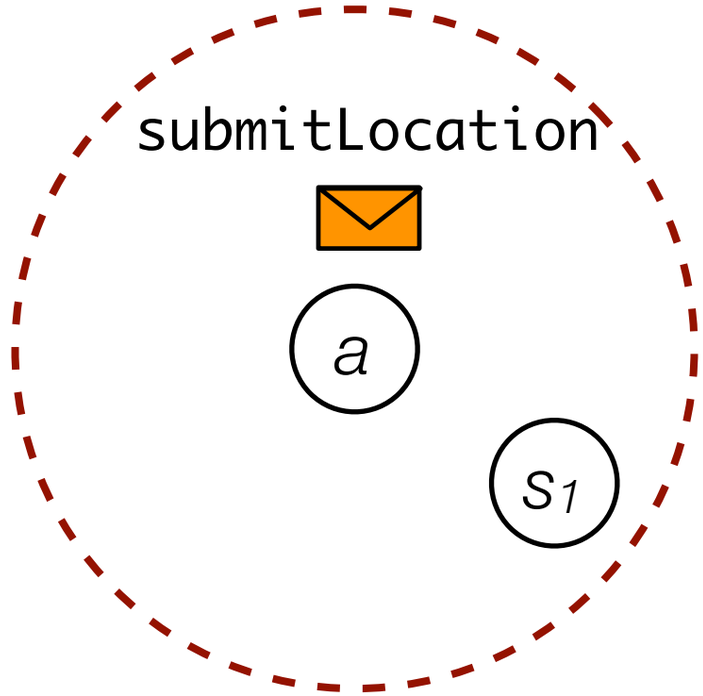



```
def ap := ambient: LocationService;
def updateLocation(newLoc) {
   ap<-submitLocation(id,newLoc)@[One,Sustain,Oneway];
}
```

Example: Location Tracker

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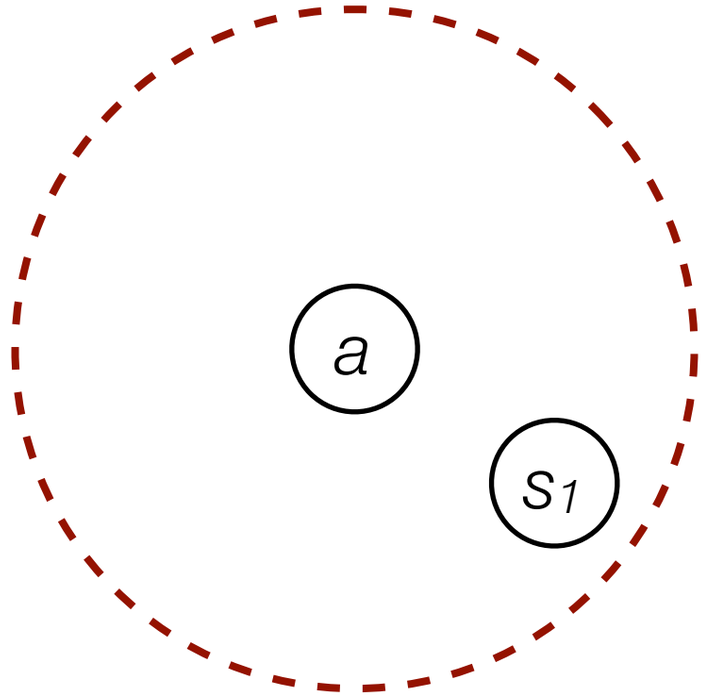


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```
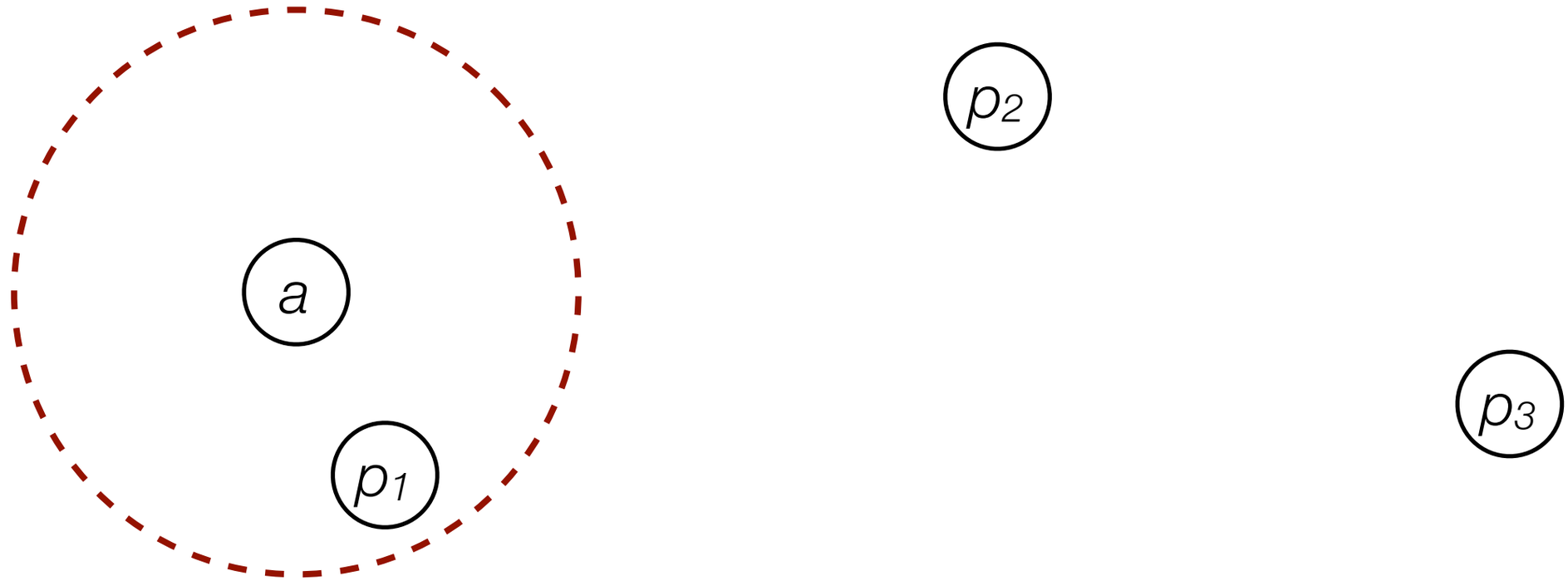
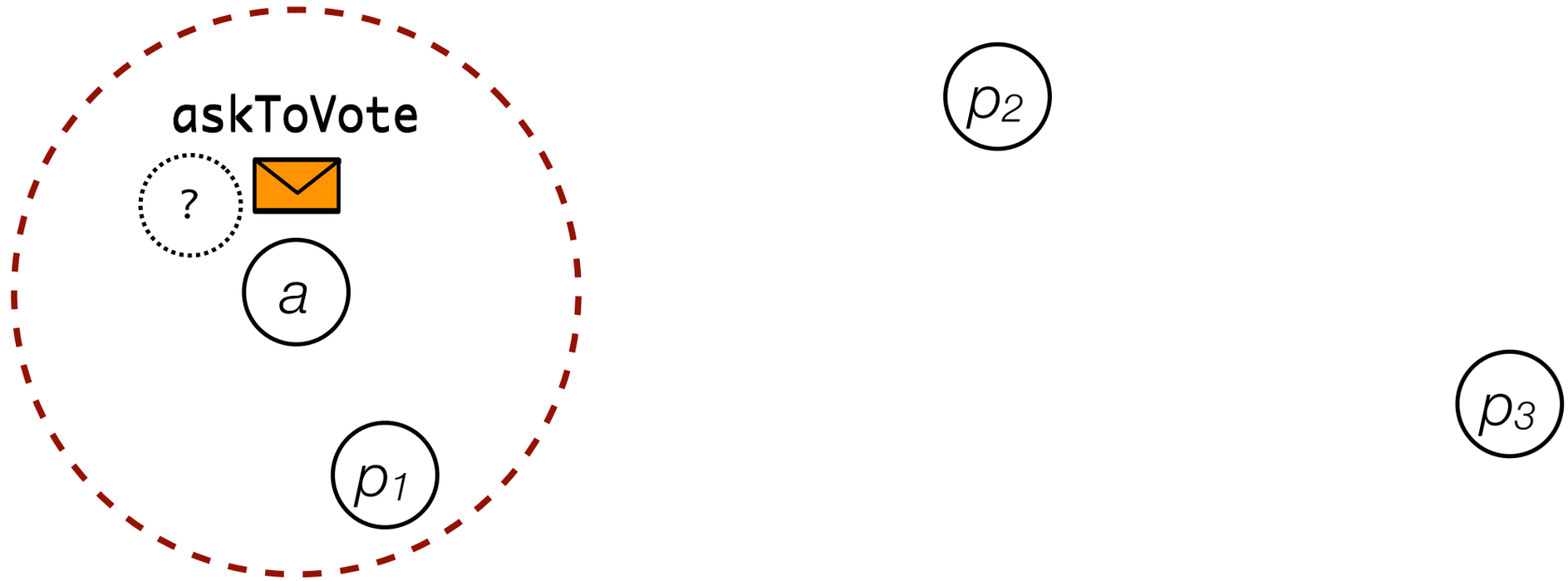

Example: Voting




```
def players := ambient: Player where: { |p| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
whenAll: handle.future resolved: { |votes|
  // process the votes
} ruined: { |exceptions|
  // ignore faulty players
}
```

Example: Voting

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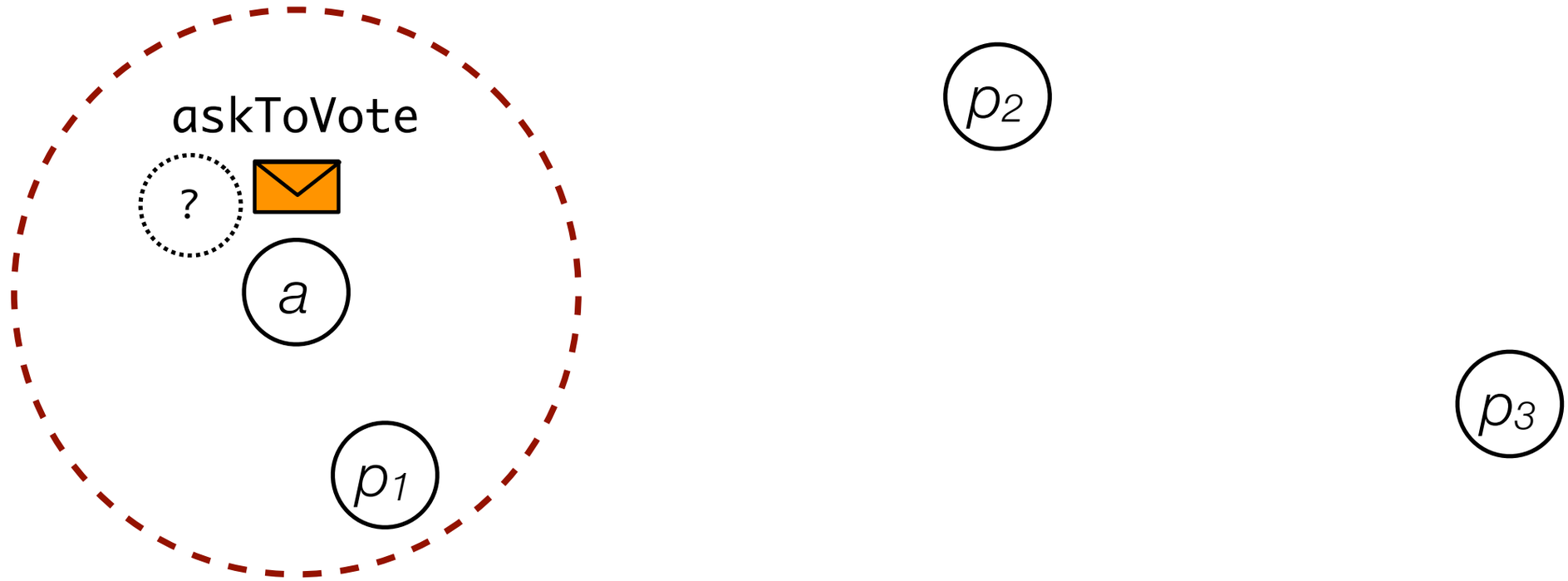


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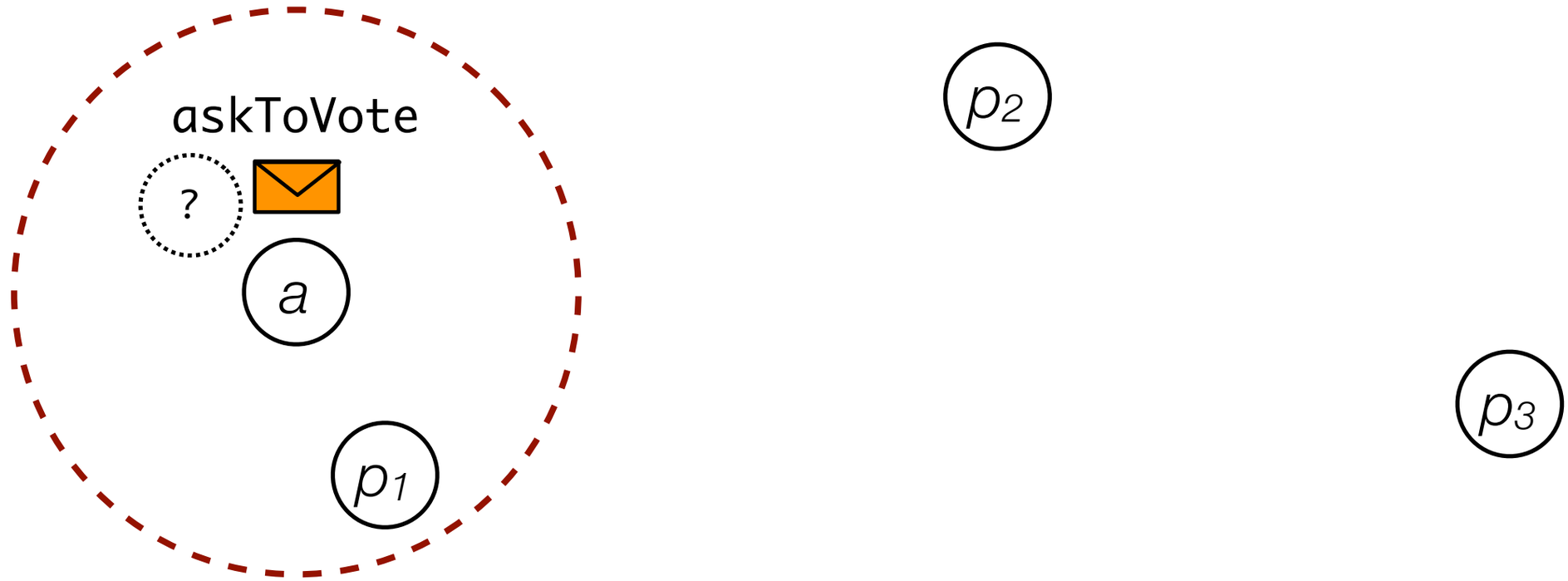


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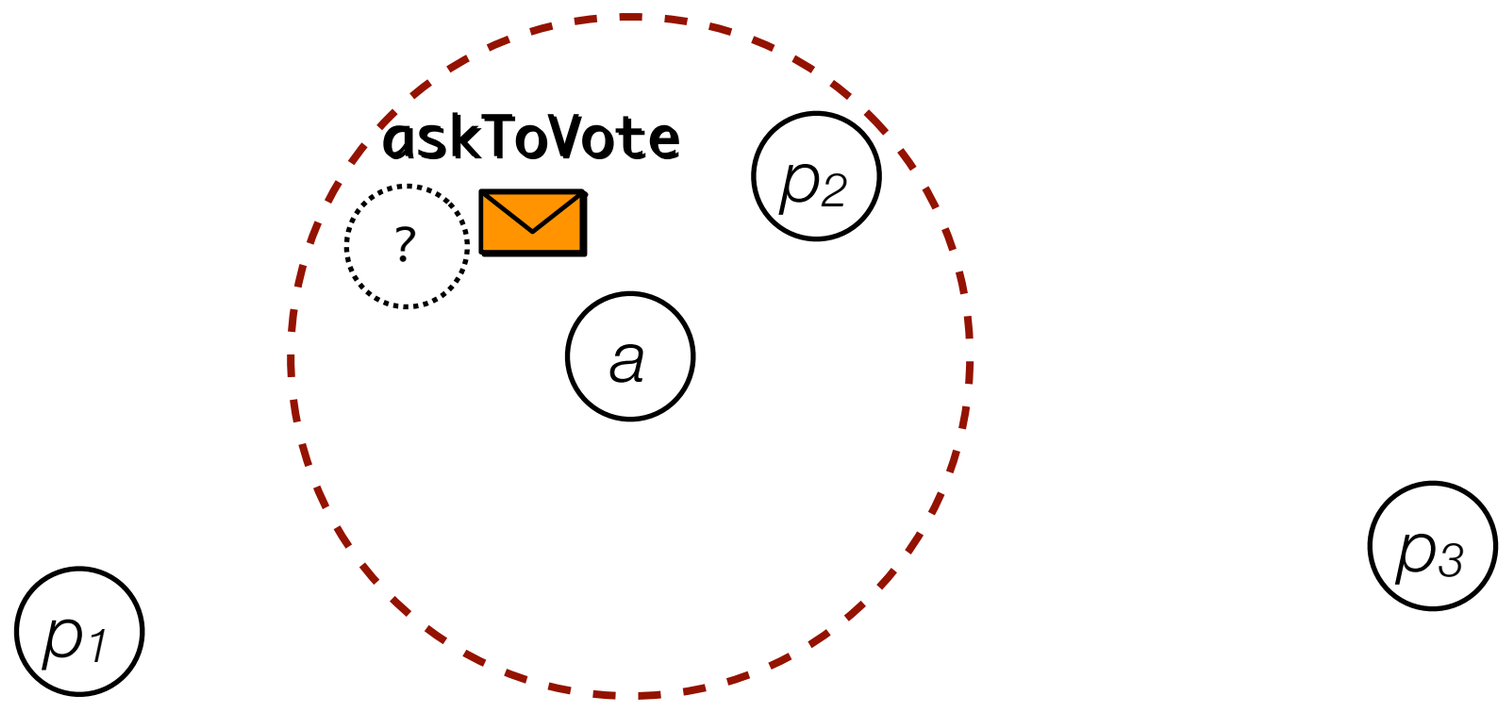


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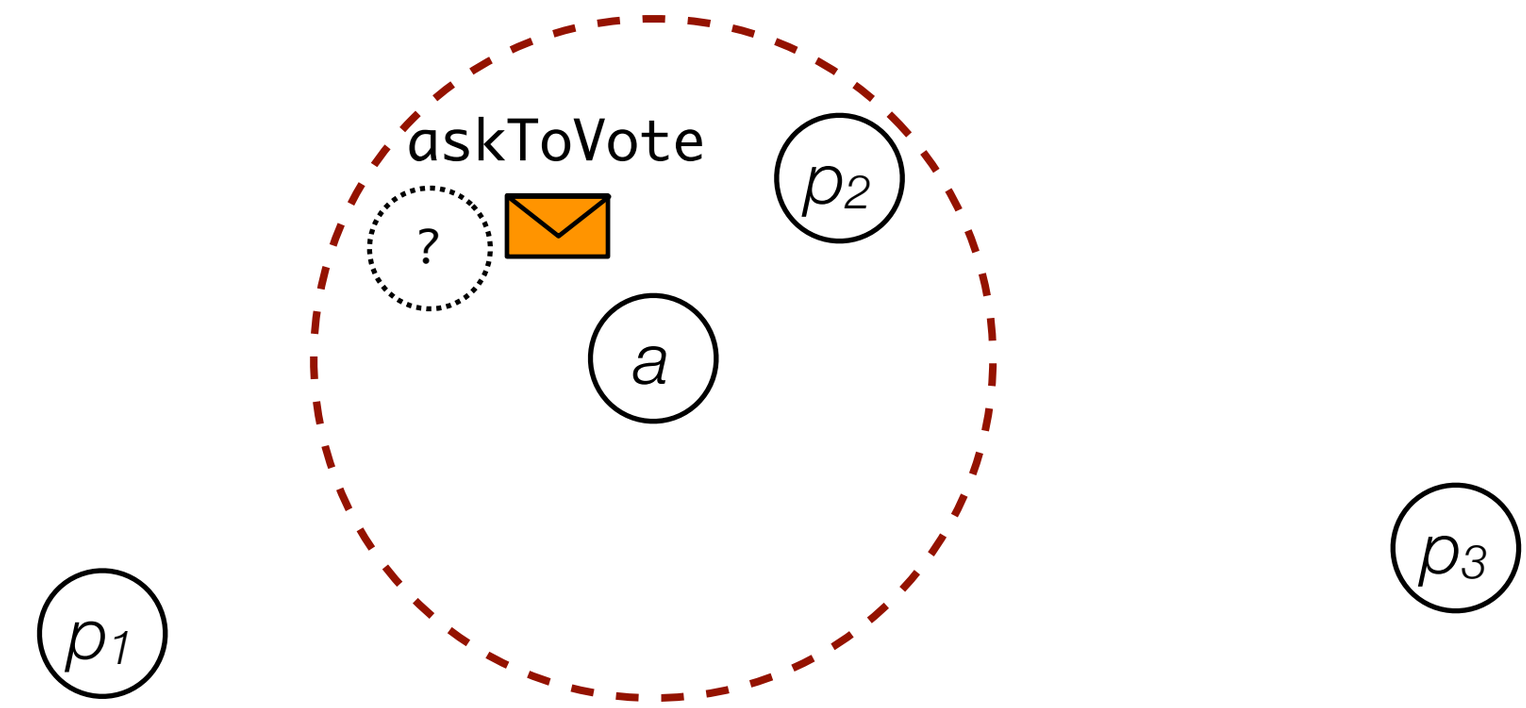


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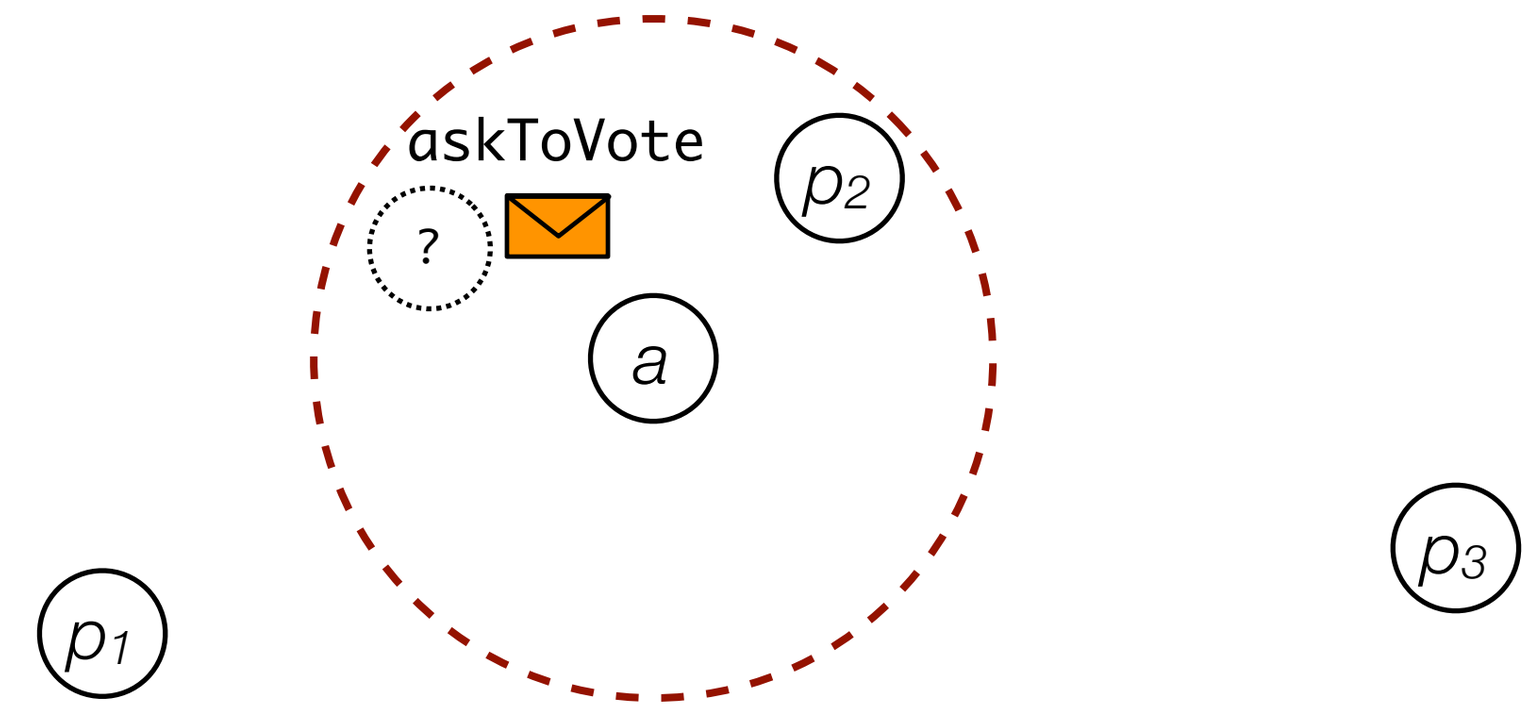


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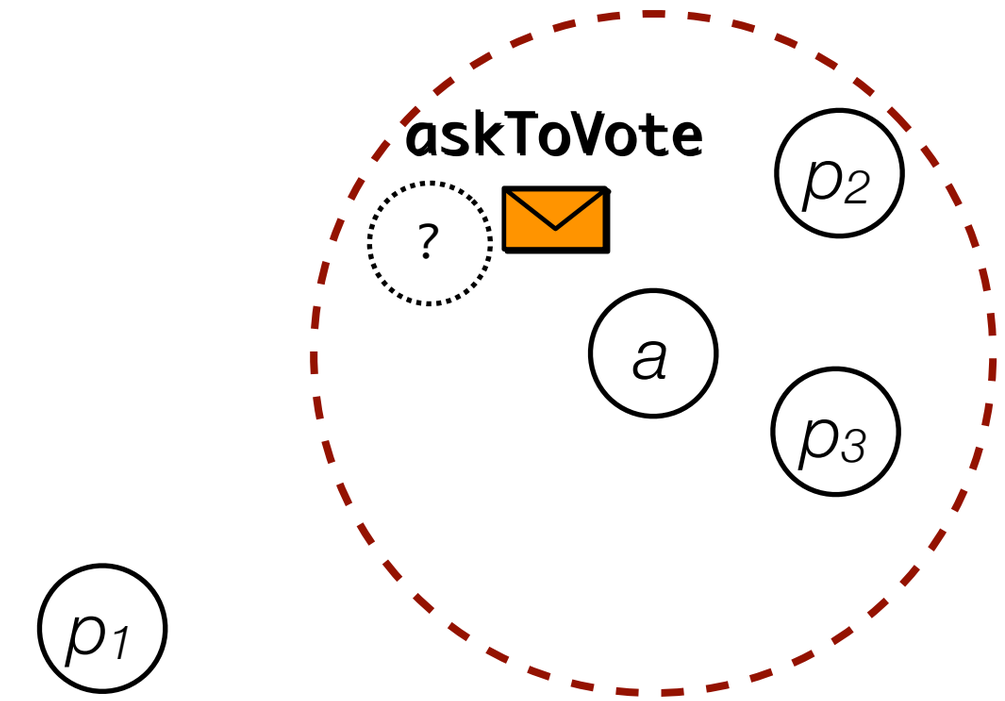


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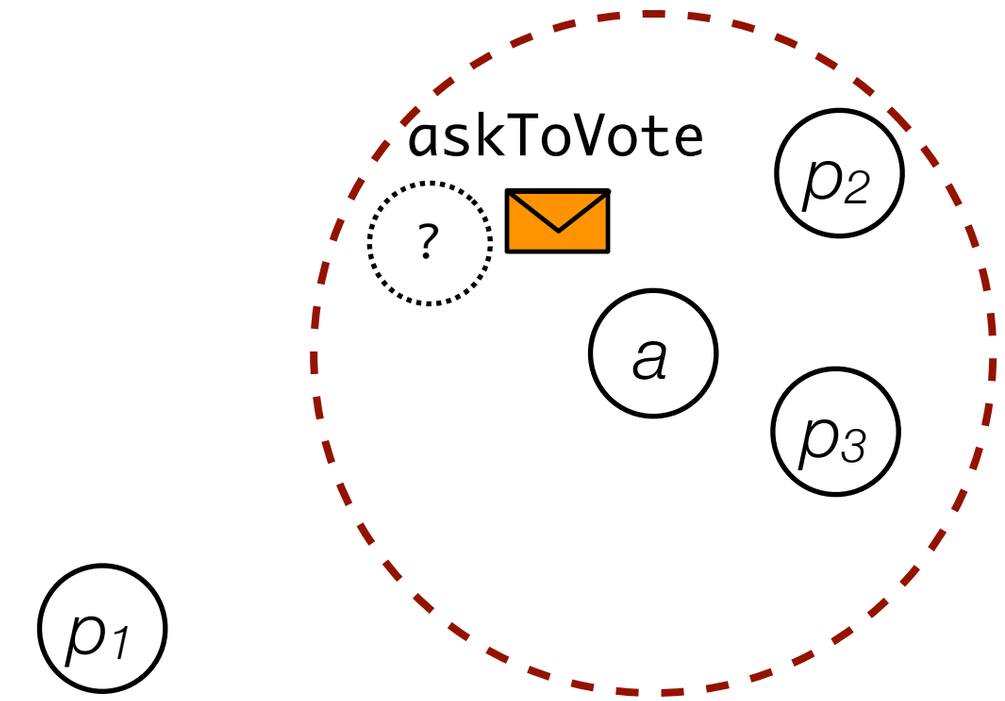


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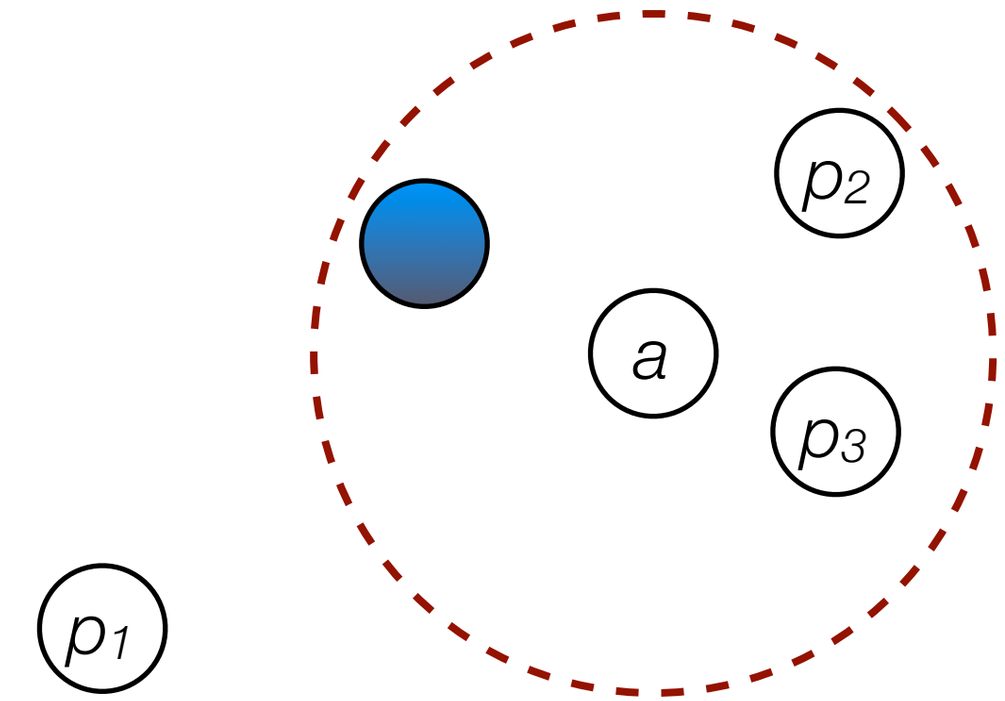
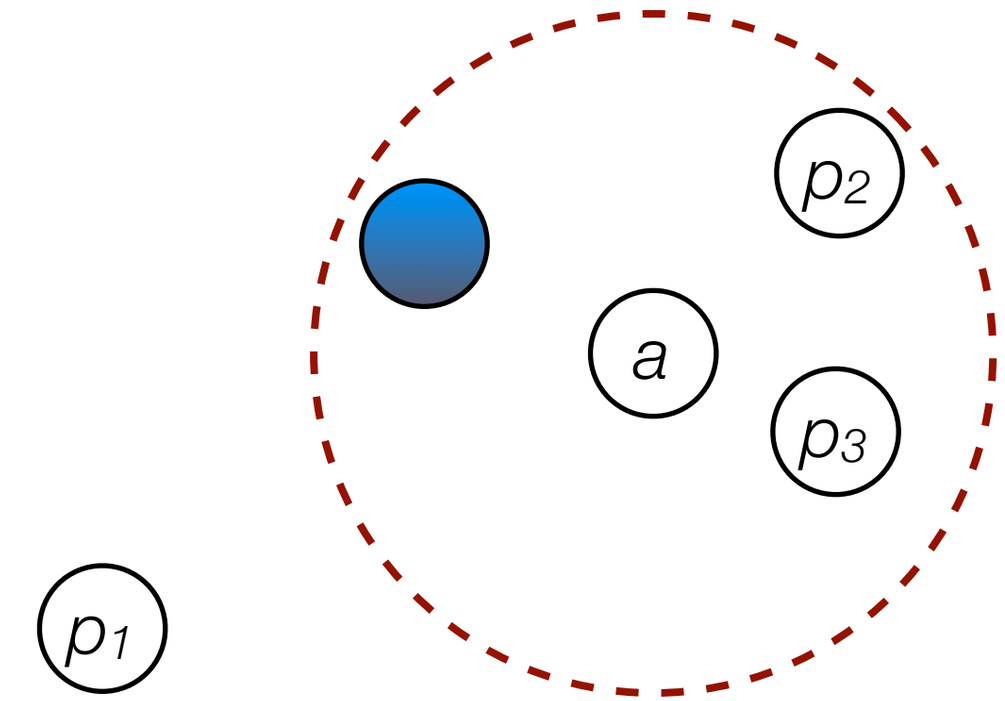
Example: Voting




```
def players := ambient: Player where: { |p| p.team == “blue” }
def handle := players<-askToVote(q)@[All,Expires(minutes(1))];
whenAll: handle.future resolved: { |votes|
  // process the votes
} ruined: { |exceptions|
  // ignore faulty players
}
```

Example: Voting

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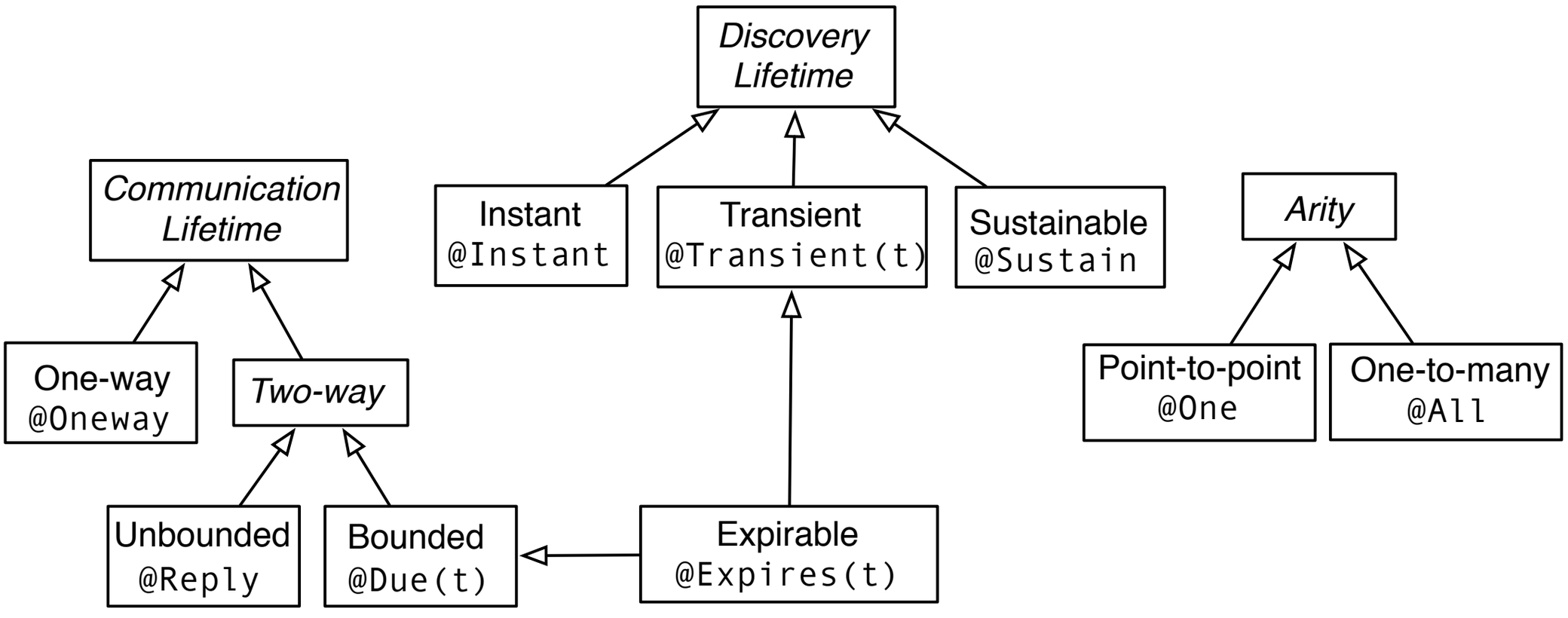
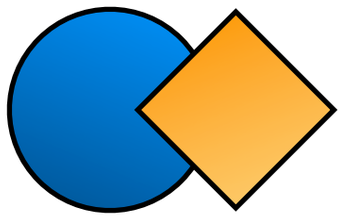
Delivery Policies



Roadmap

Motivation



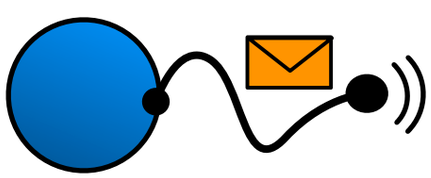
Object-event impedance mismatch

Coordination

Mobile ad hoc networks

Contribution

AMBIENTTALK



Ambient References

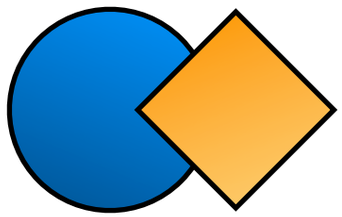
Validation

Evaluation

Implementation

Evaluation

Motivation



Object-event impedance mismatch

Issues

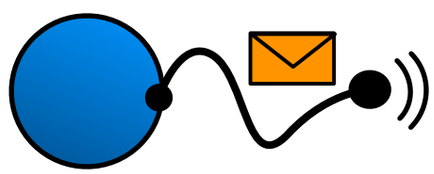
Coordination

Criteria

Contribution

Language

Language Feature



Ambient References

Validation

Evaluation

Implementation

Mobile ad hoc networks

Criteria Revisited

	AmbientTalk	Ambient References

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Decentralised Discovery	`whenever:discovered:`	Can encode discovery

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Criteria Revisited

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Space-decoupled communication		`ambient:` description

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Arity-decoupled communication		`@All`

Criteria Revisited

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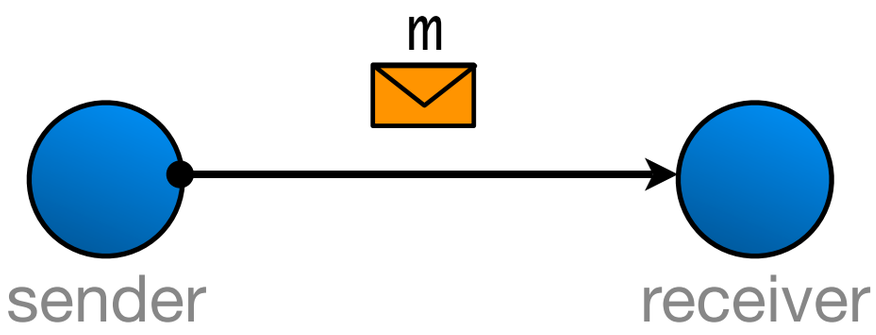
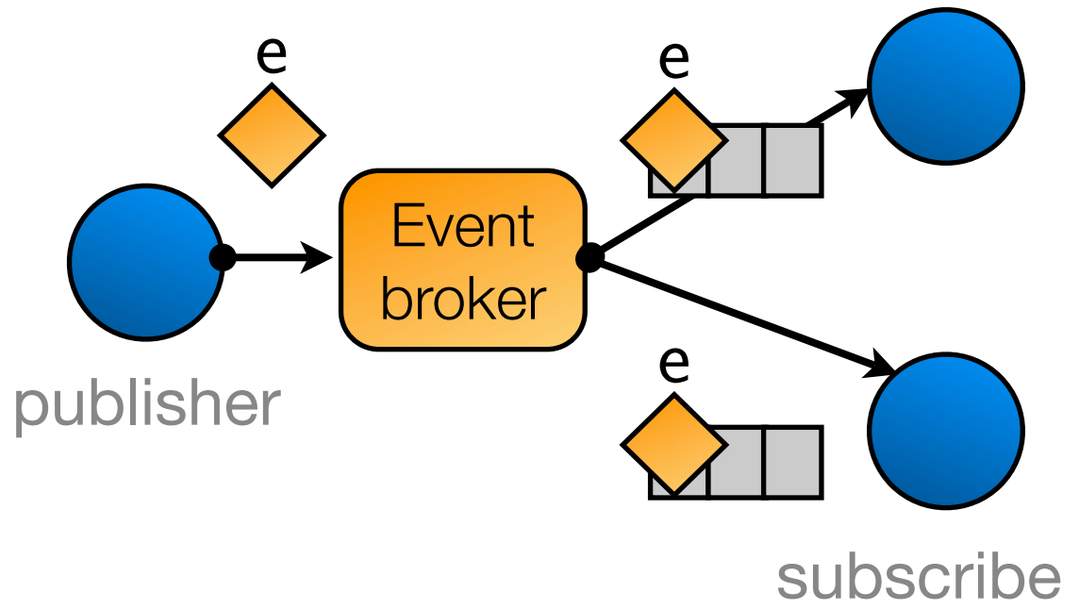
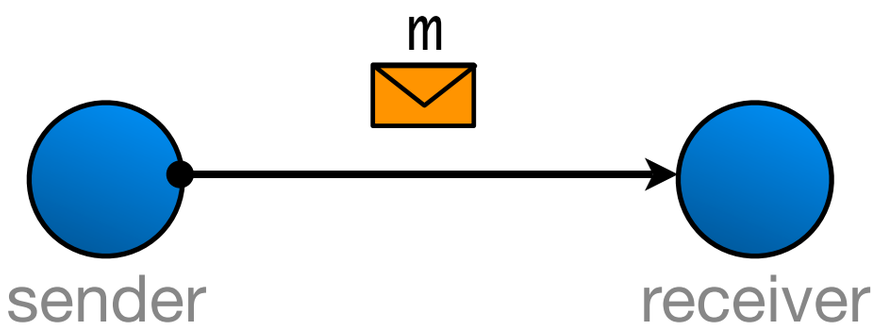
Arity-decoupled communication		`@All`
Connection-independent Failure handling	`@Due`, Leasing	`@Expires`

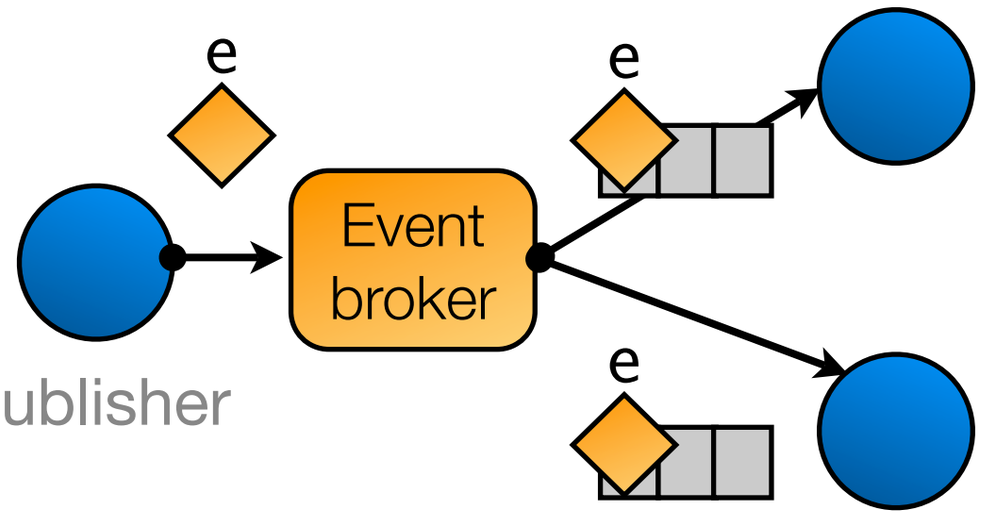
O/E Impedance Mismatch Revisited

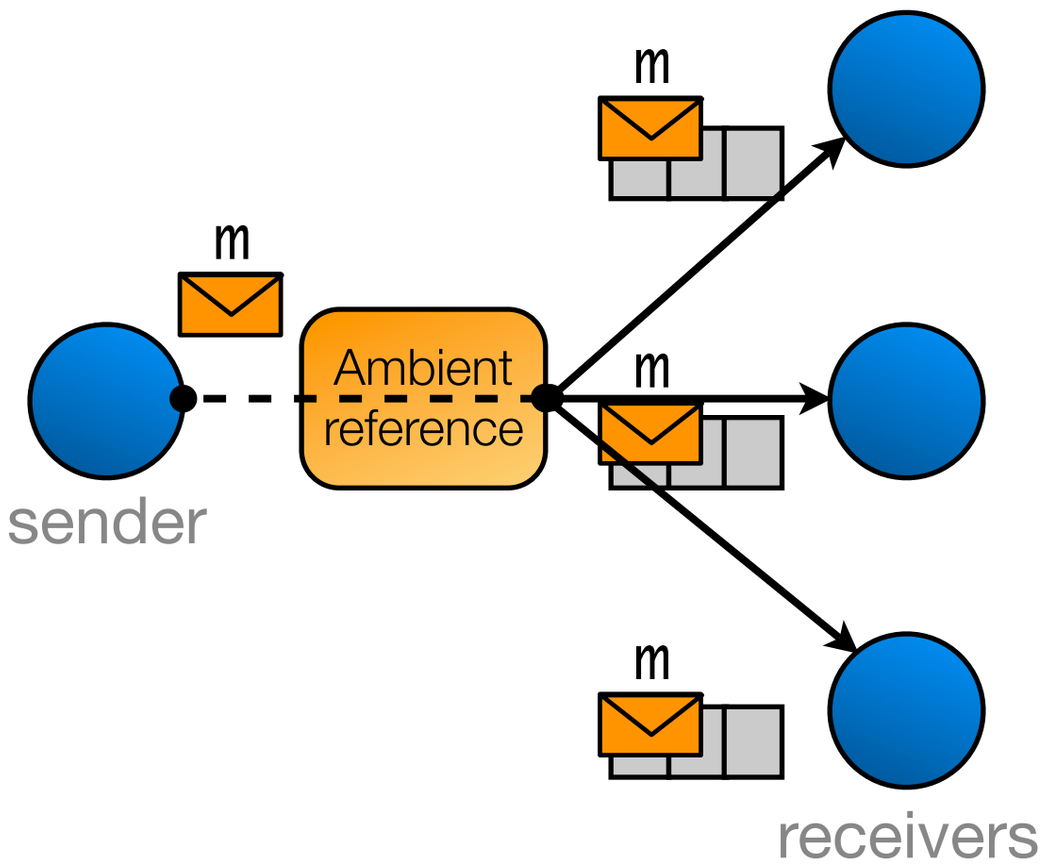




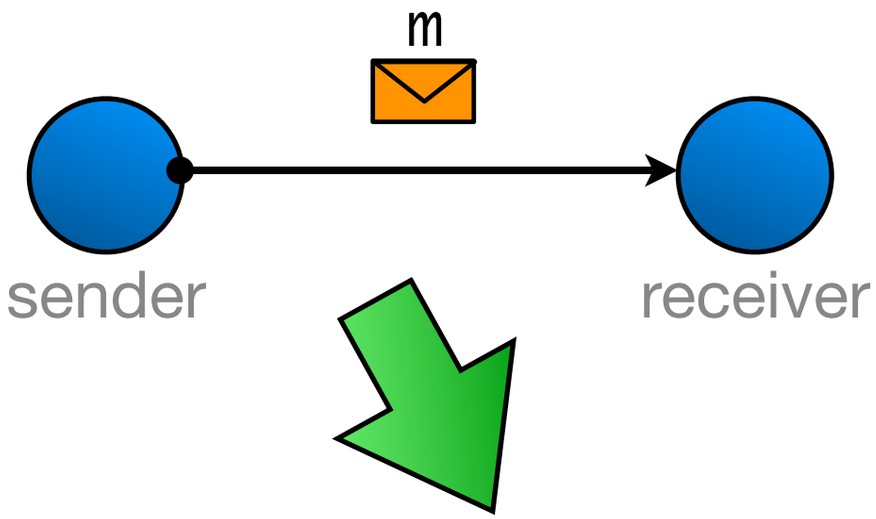
O/E Impedance Mismatch Revisited

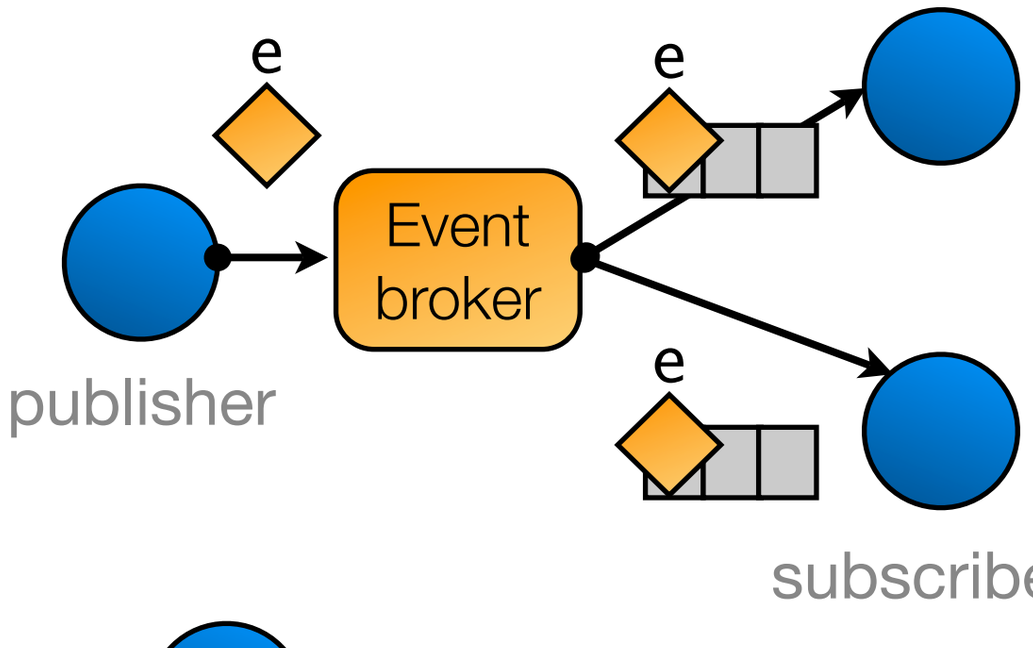


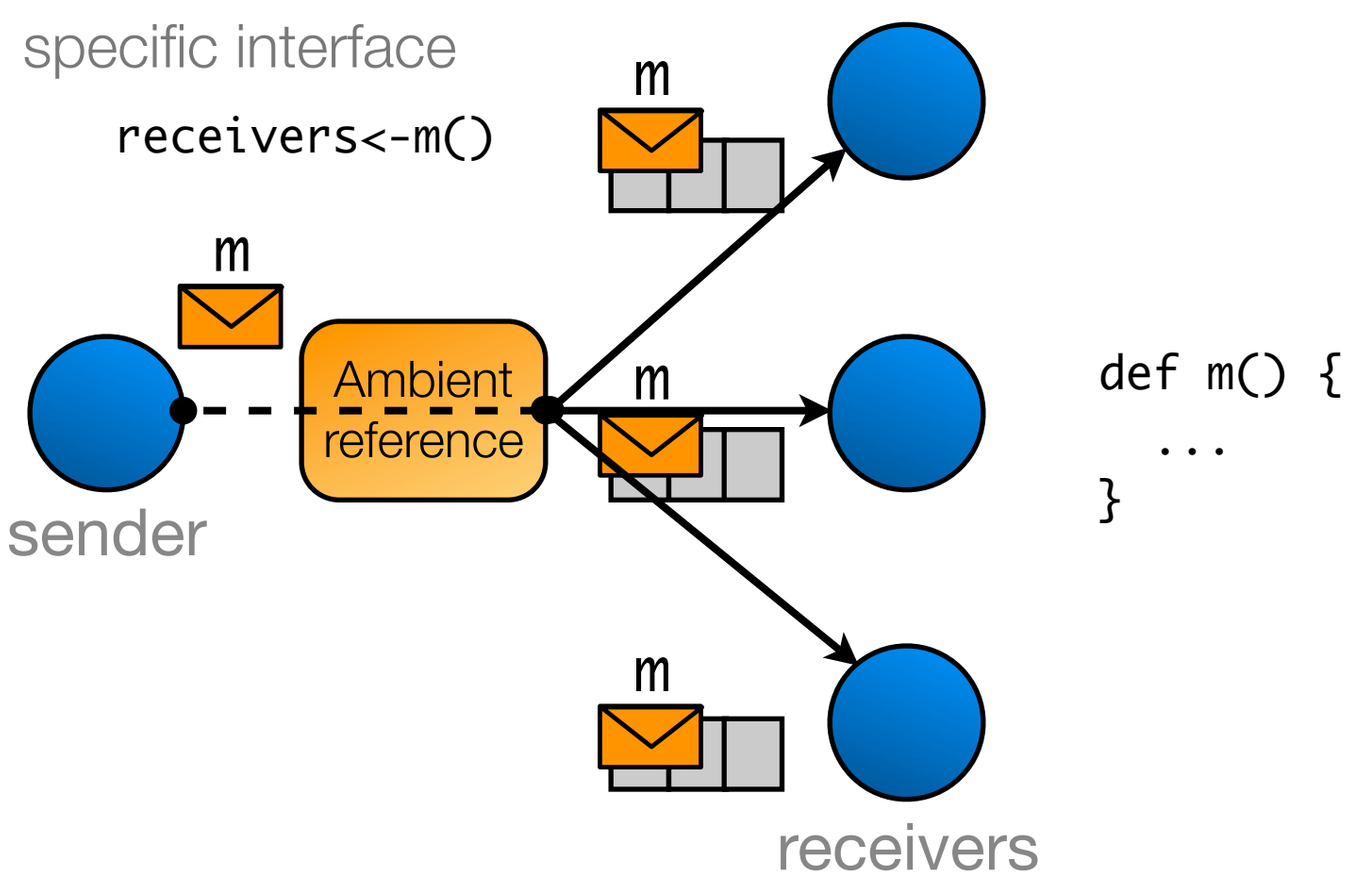




O/E Impedance Mismatch Revisited

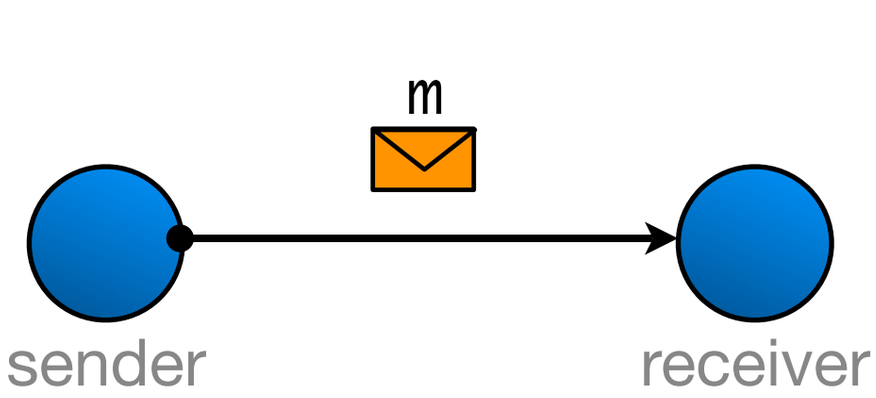


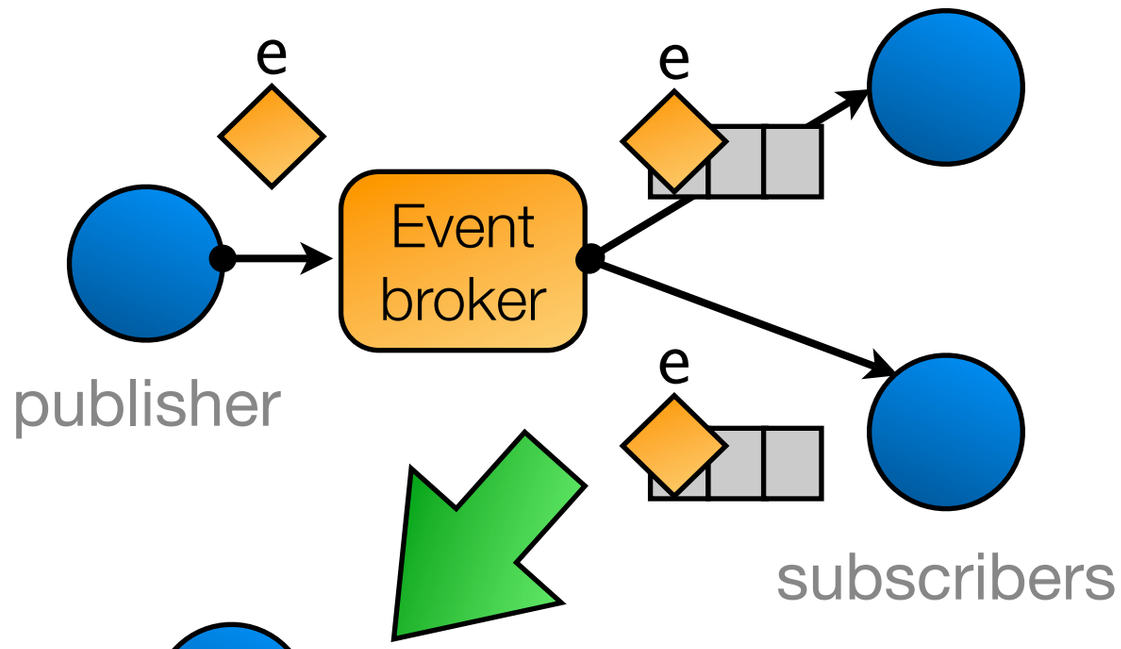


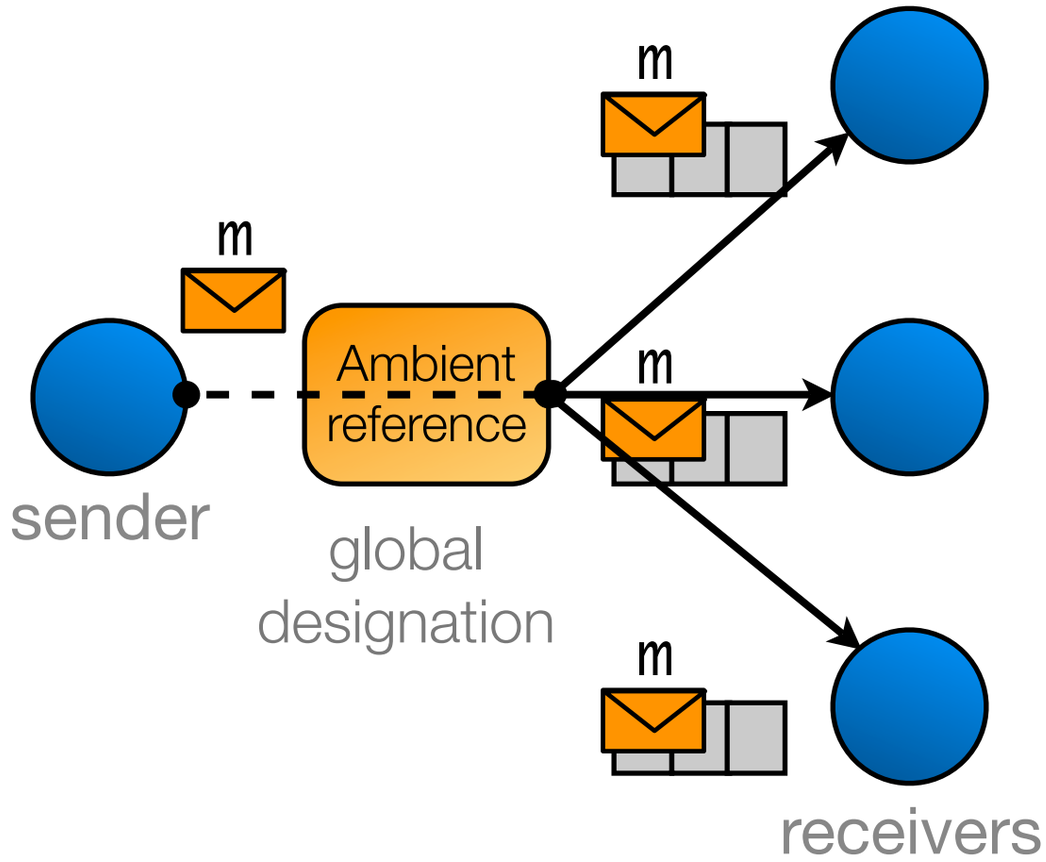



```
def m() {
   ...
}
```

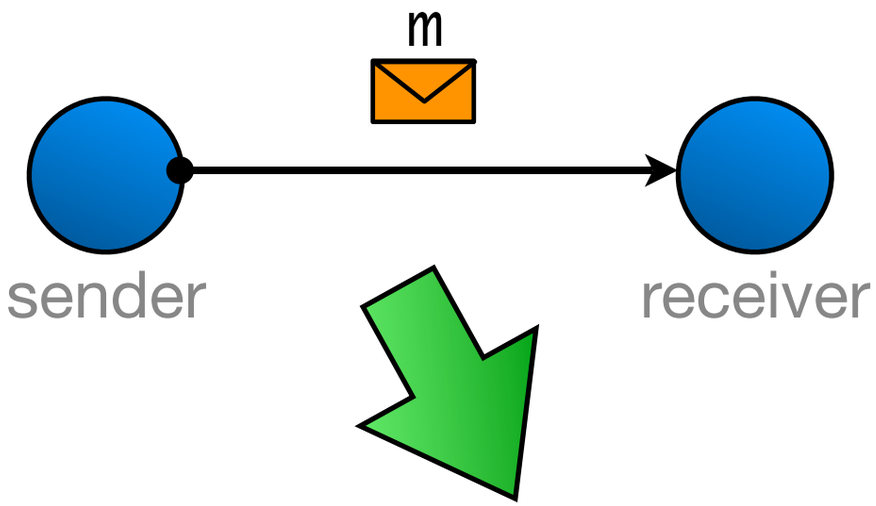
O/E Impedance Mismatch Revisited

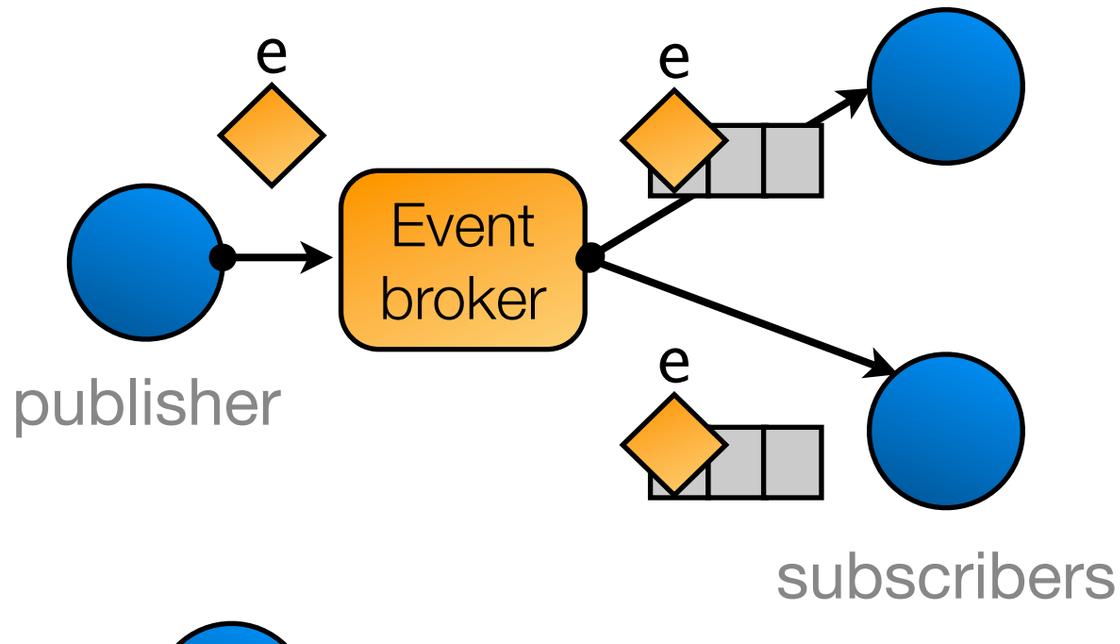


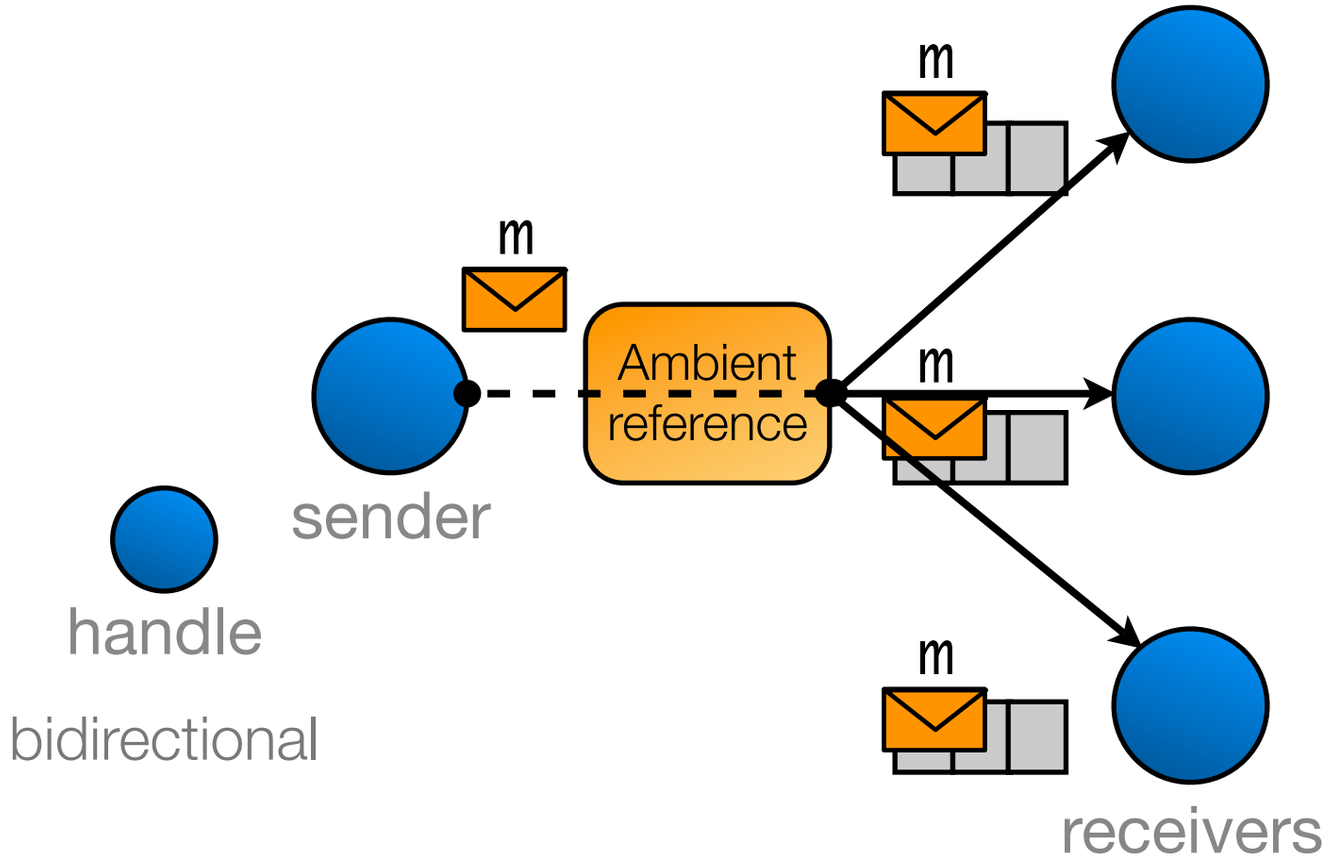




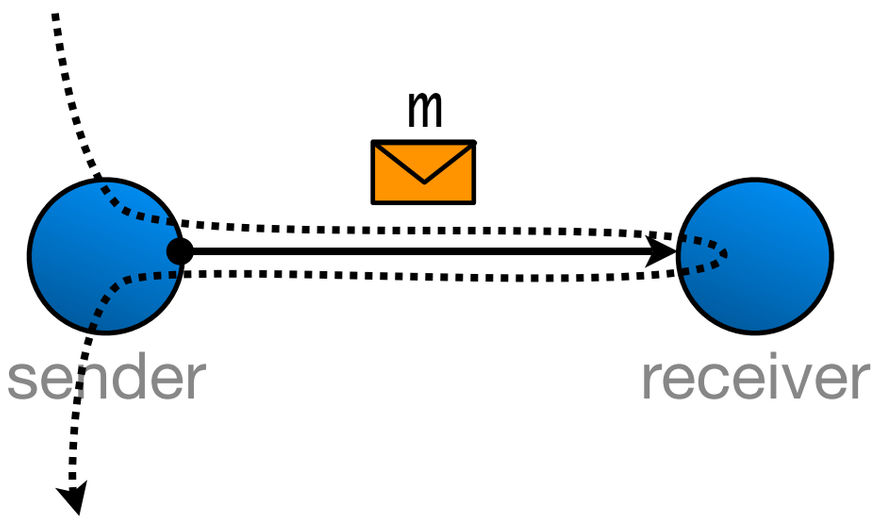
O/E Impedance Mismatch Revisited

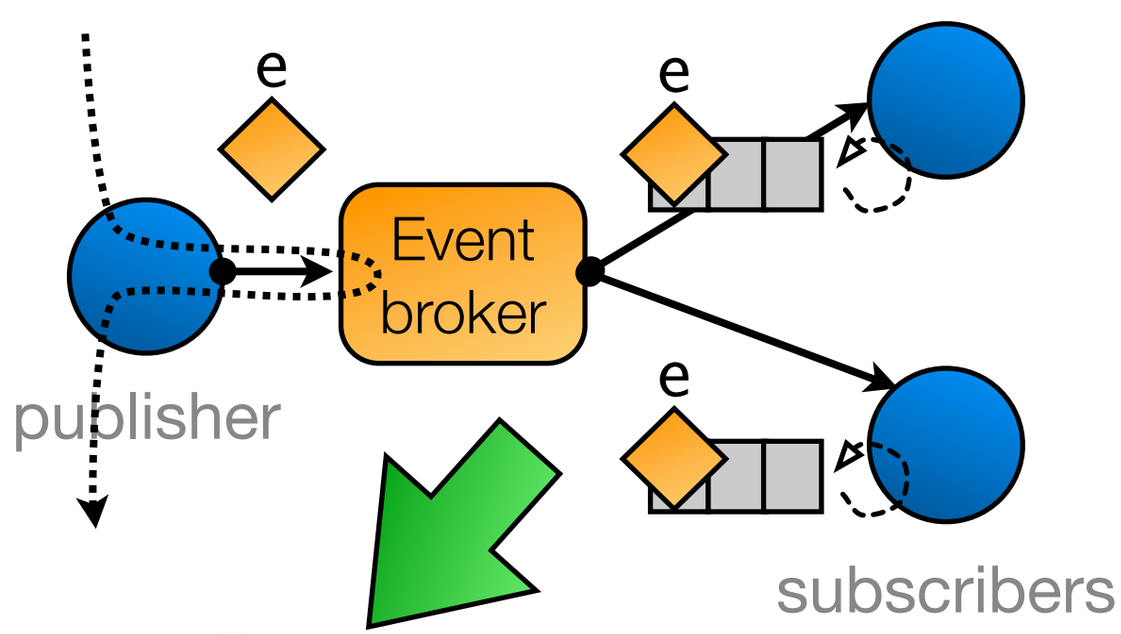


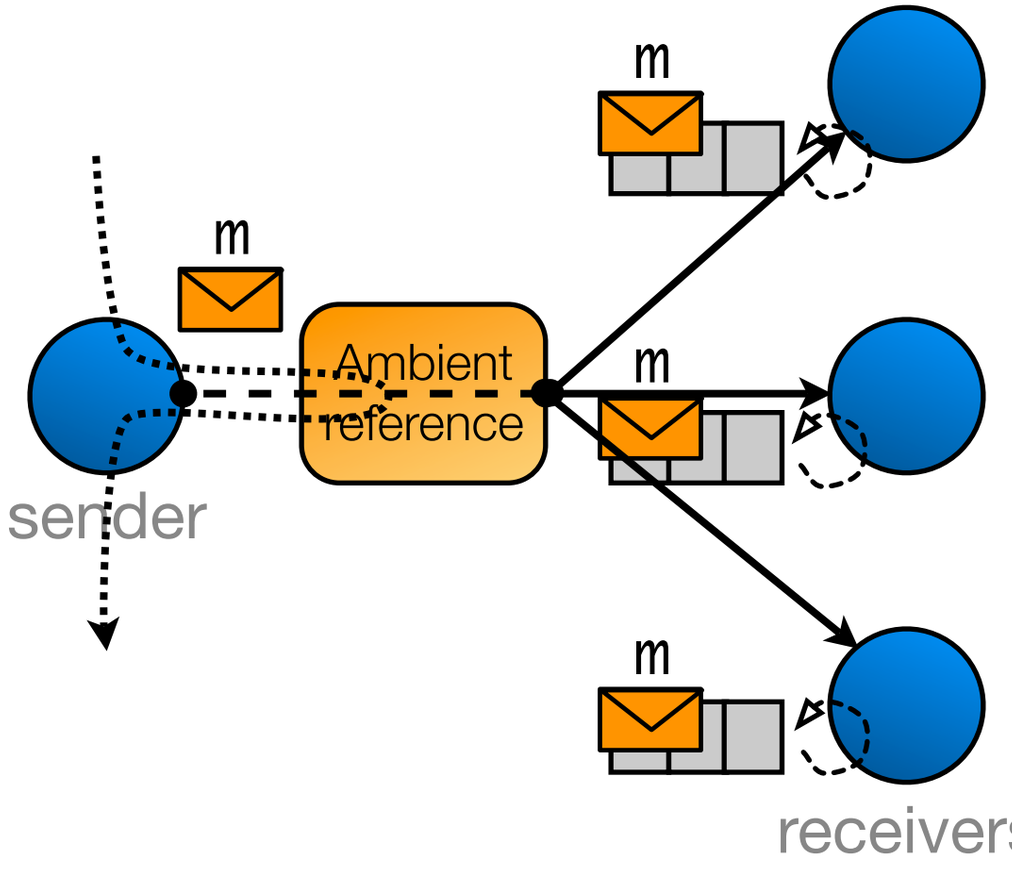




O/E Impedance Mismatch Revisited



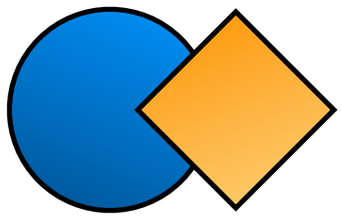




event loops

Roadmap

Motivation



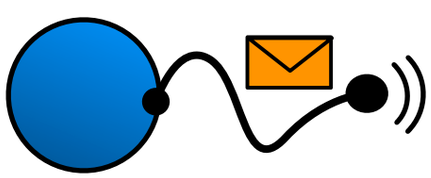
Object-event impedance mismatch

Coordination

Mobile ad hoc networks

Contribution

AMBIENTTALK



Ambient References

Validation

Evaluation

Implementation

Implementation & Validation

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Object-event impedance mismatch

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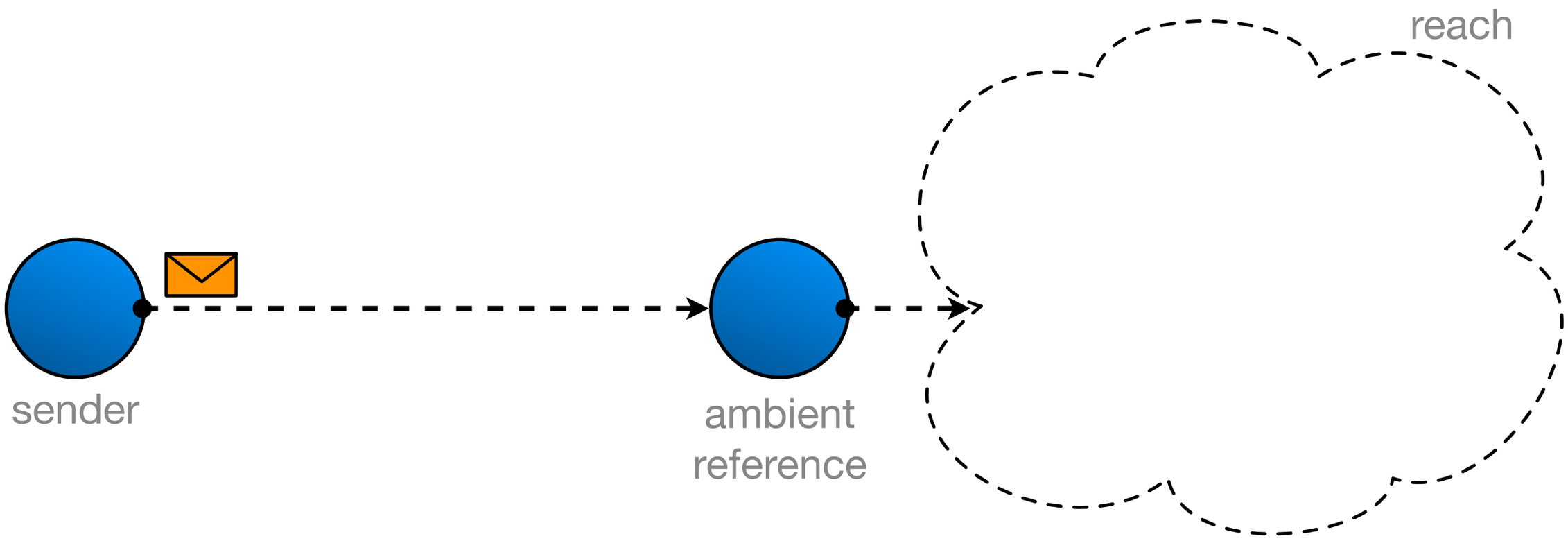
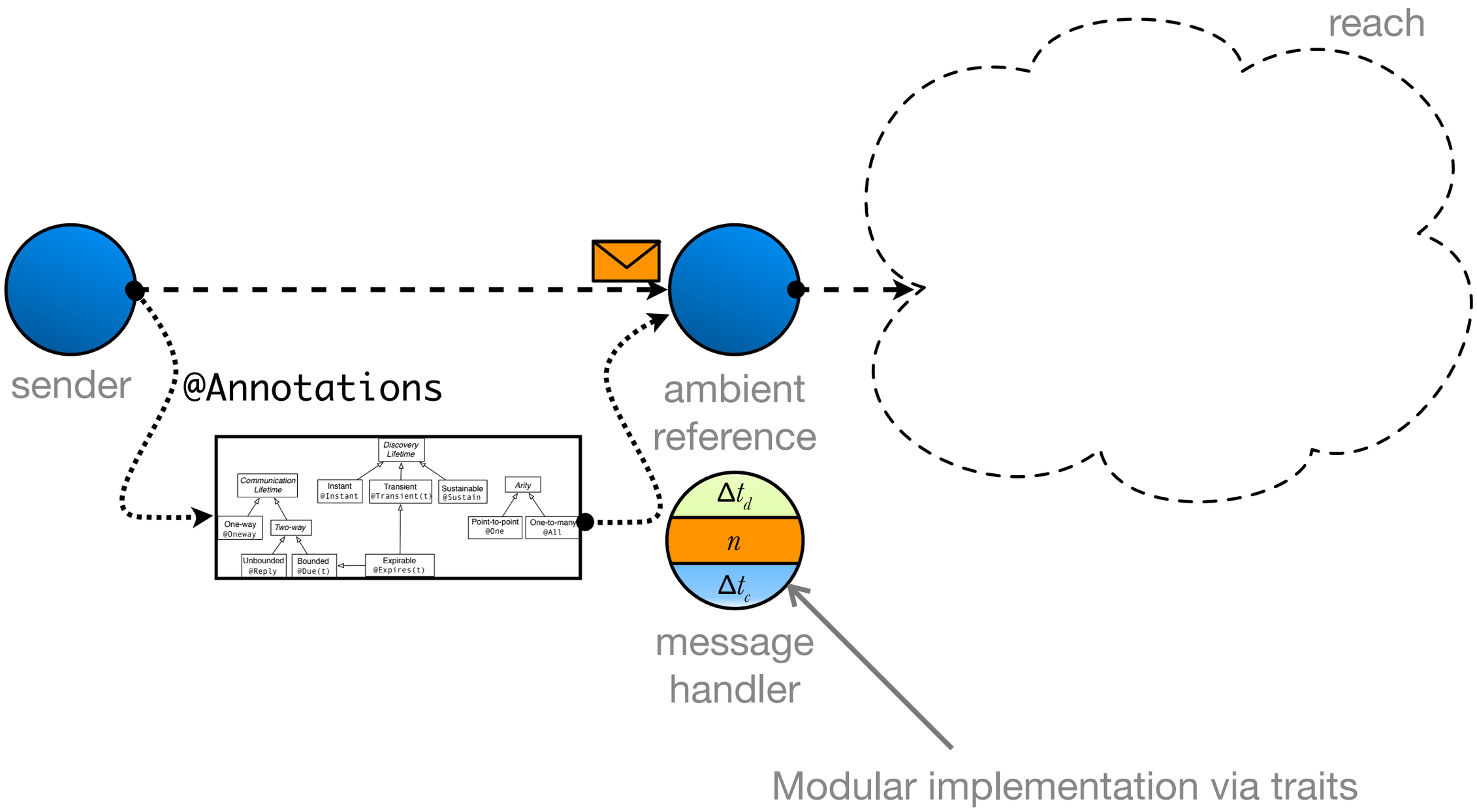


Implementation



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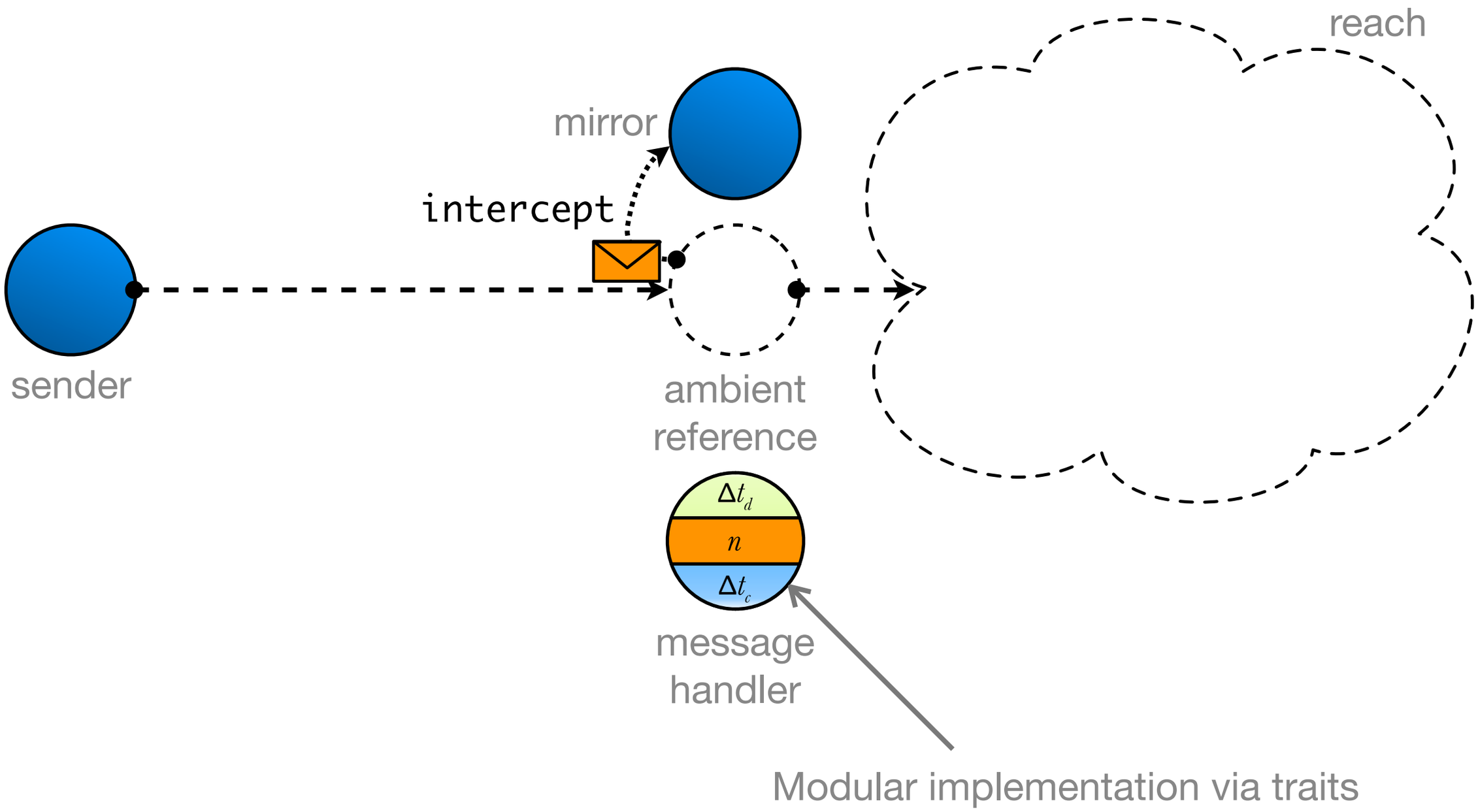

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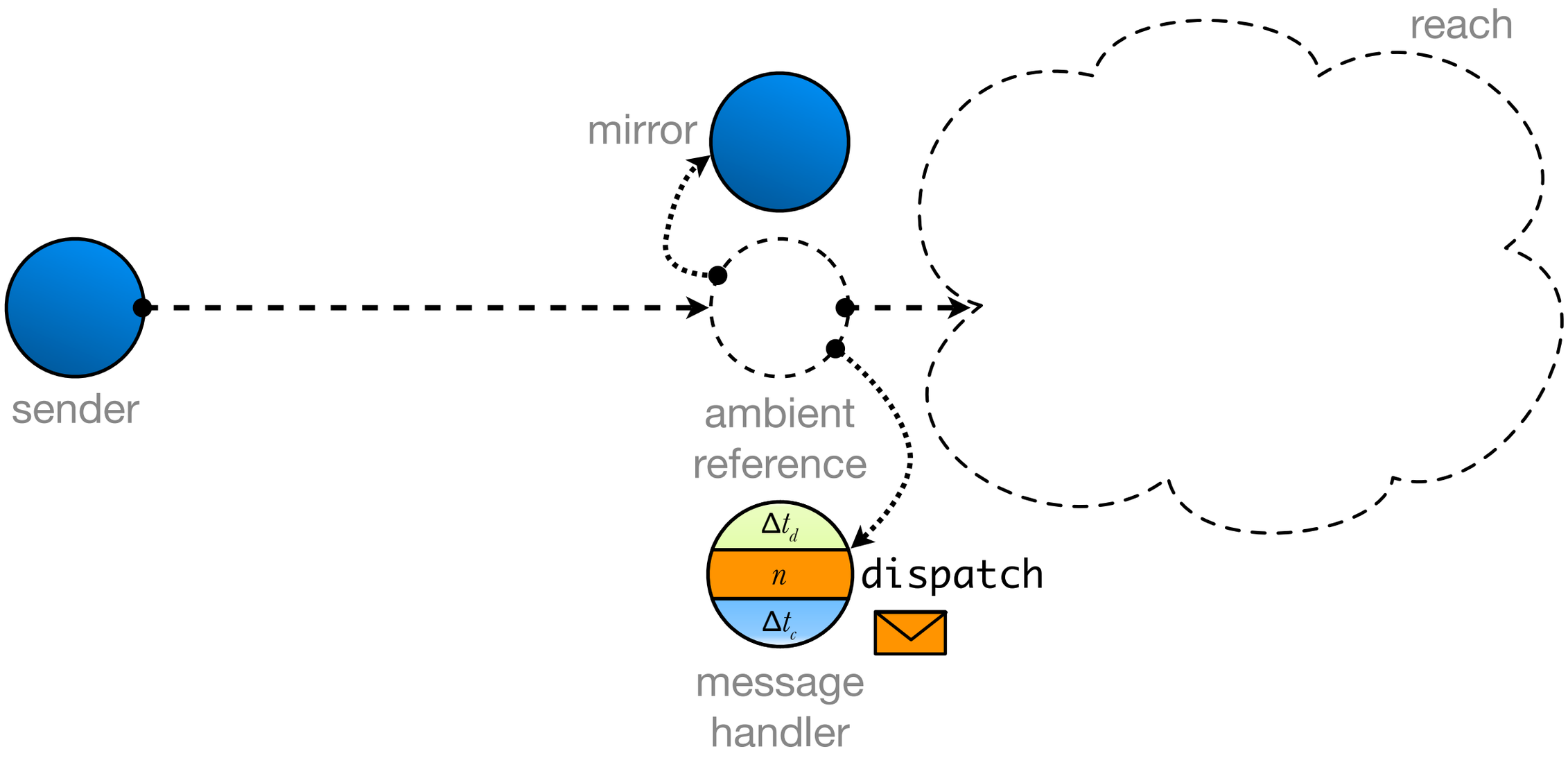

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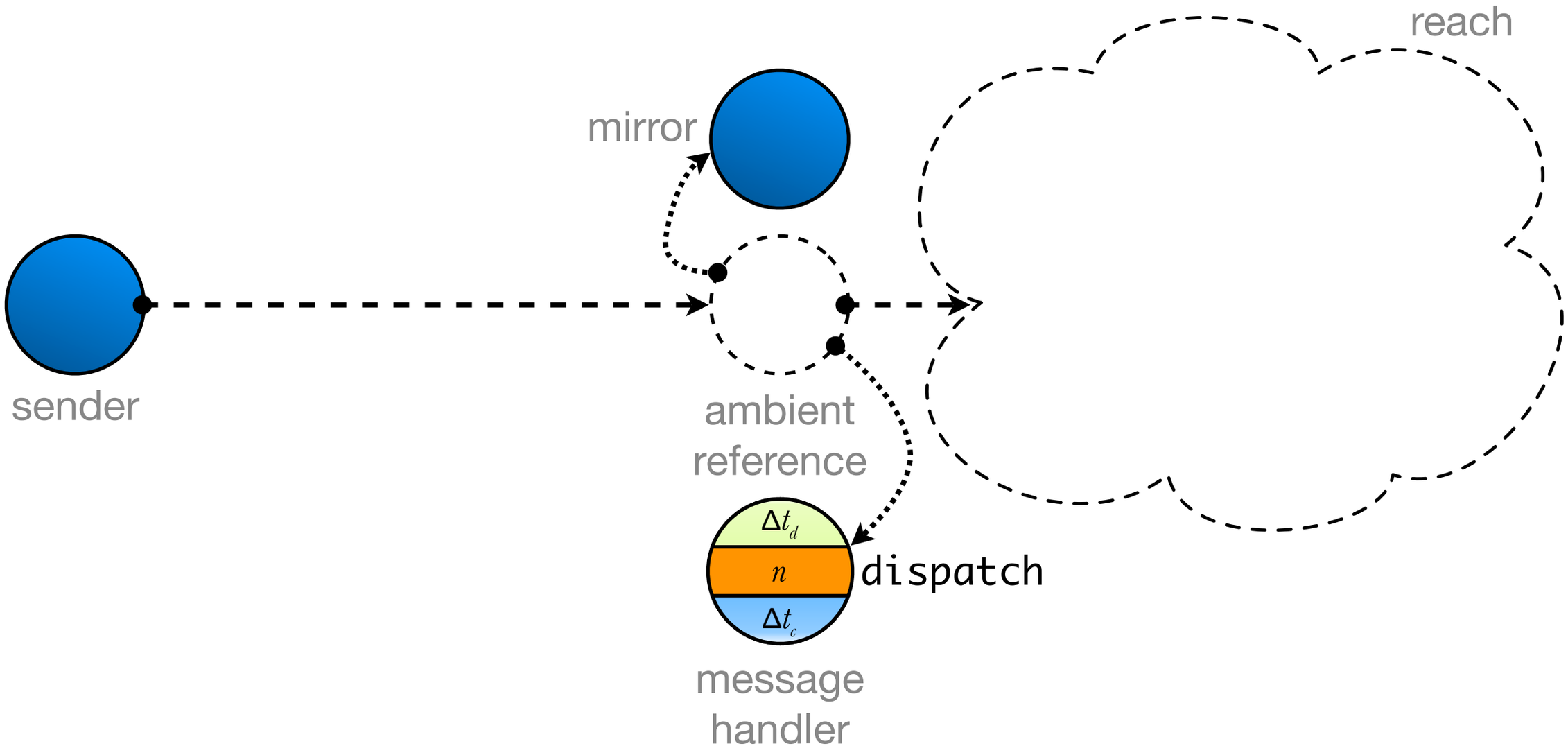

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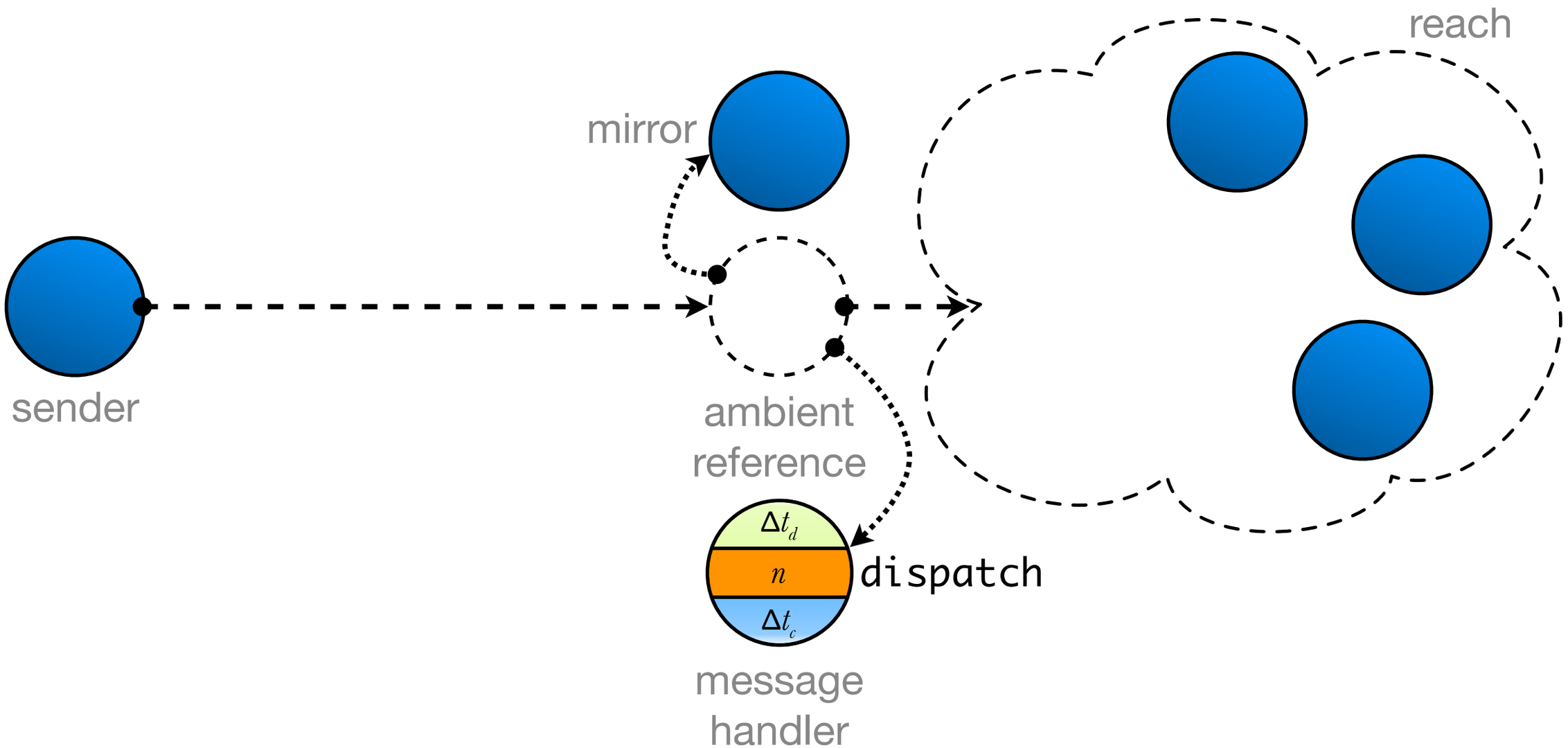

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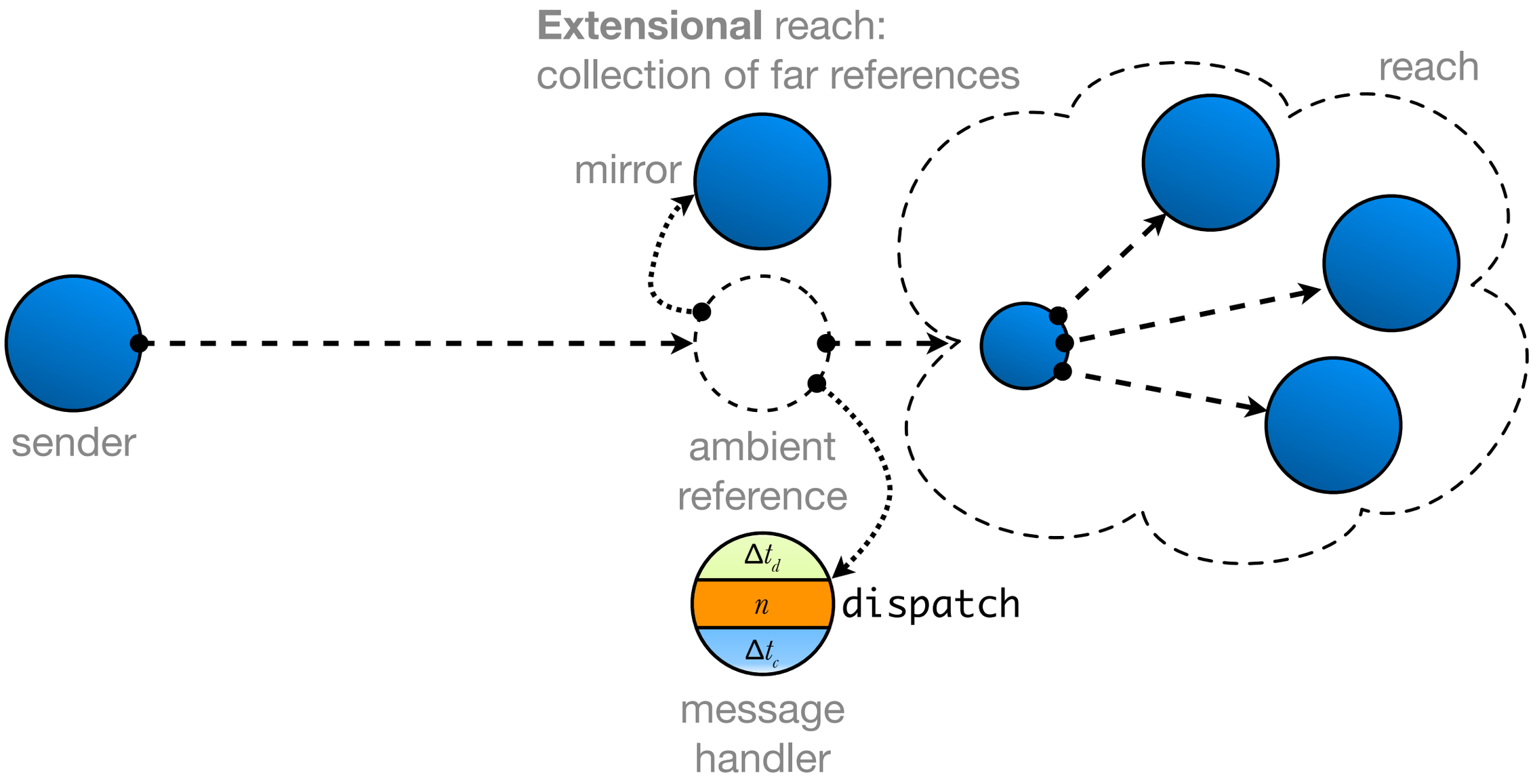

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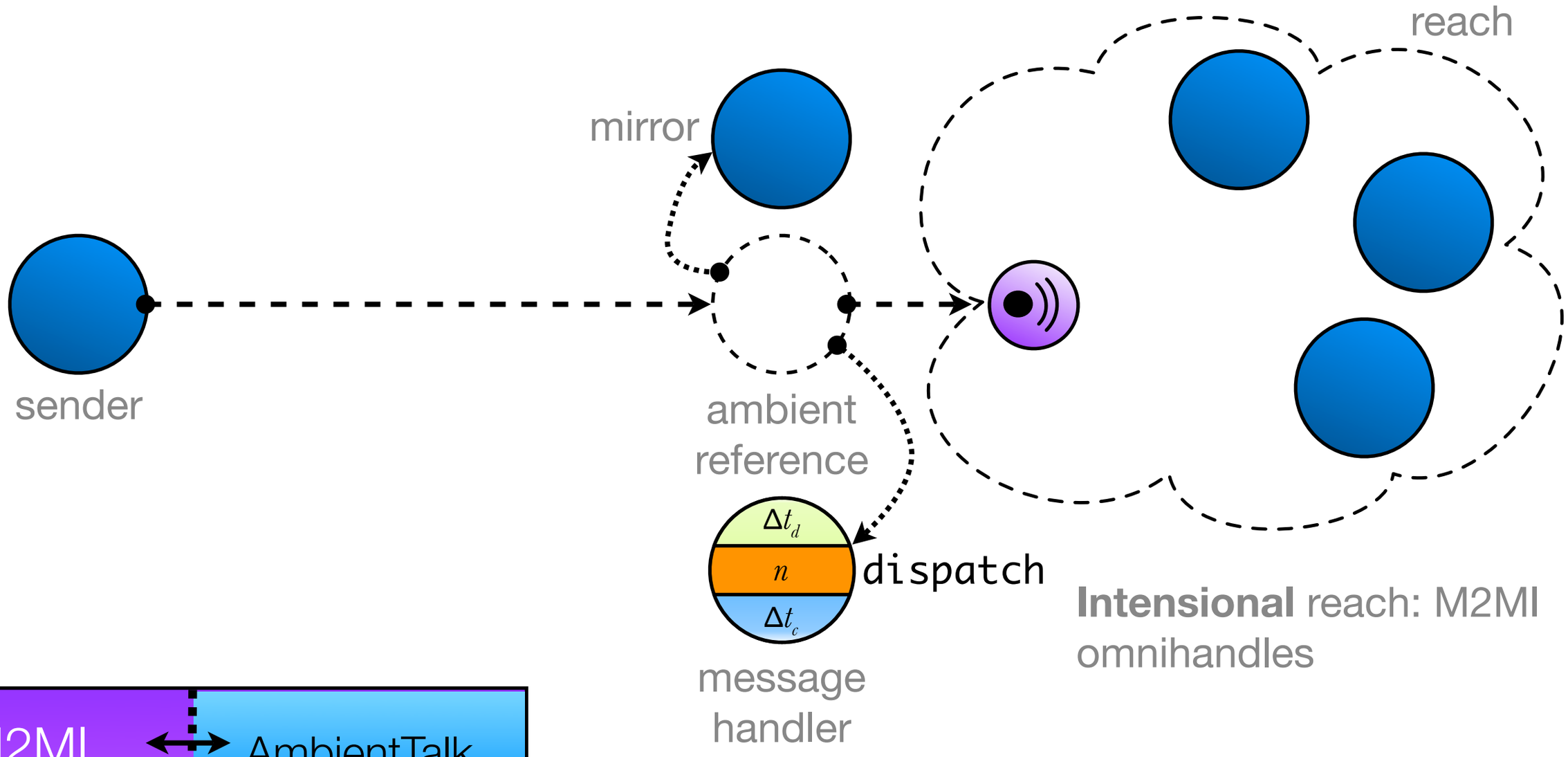
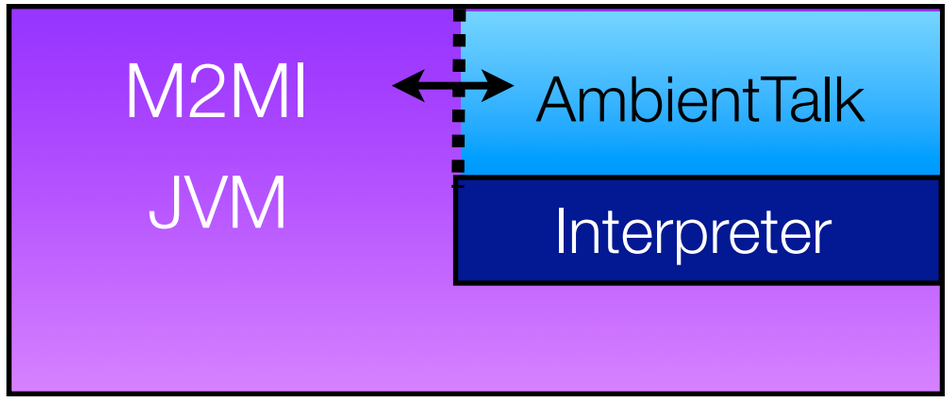




Linguistic Symbiosis

Validation

Ambient References

M2MI [Kaminsky & Bischof 02]

Validation

Ambient References

M2MI [Kaminsky & Bischof 02]

← Collaborative Chat

← Collaborative Slideshow

Validation

Ambient References

M2MI [Kaminsky & Bischof 02]

Collaborative Chat

Collaborative Slideshow

Location Tracker

Voting

Validation

Ambient References

M2MI [Kaminsky & Bischof 02]

Collaborative Chat

Collaborative Slideshow

Location Tracker

Voting

- Thread Synchronisation
- Explicit callbacks
- Explicit scheduling code
- No dynamic attributes

Concluding Remarks

Future Work

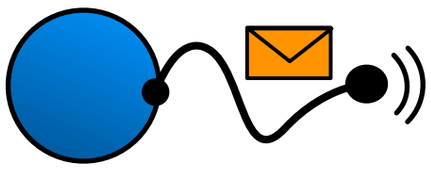
Service Discovery: ontologies, describing services, ...

Security: controlling **visibility** of exported objects & ambient references

More **efficient** implementation strategies

Conclusion

- Ambient-oriented Programming = “OOP in MANETs”
  - Object communication: decoupled in time & synchronisation [Dedecker 06]
  - Object **designation**: decoupled in space & arity
- Ambient references: **intensional** remote object references



- Unification of OO and event-based publish/subscribe interaction