A Prototype-based Approach to Distributed Applications

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Overview

- Context
- Prototype-based languages
  - Pic%
- Concurrent languages
  - cPico
- Distributed languages
  - Advantages of prototypes
  - dPico
- Future Work & Conclusions

Context: Ambient Intelligence

- Evolution towards increasingly smaller mobile devices embedded in the environment
- User is surrounded by a ‘processor cloud’ or Personal Area Network
- Programs and objects are able to move
- We need…
  - new design methodologies
  - adequate hardware support
  - runtime support, standards
  - new programming languages

Problem Statement

- Contemporary languages are not designed to write programs inhabiting complex, dynamic, flexible, open hardware constellations
- Need for a distributed (and concurrent) programming language
- Design of a distributed programming language based on the prototype-based OO paradigm
- Exploring the use of object-based inheritance in a distributed context

Language Overview

Pic%

- Prototype-based extension of Pico (D'Hondt, 1996)
- Small, minimal, exploratory object-oriented language
- Features parent sharing: two or more objects can inherit from (delegate to) the *same* parental object

cPico

- Concurrent extension of Pic%
- Features active objects and asynchronous communication
- Uses parent sharing to control mutable shared state

dPico

- Distributed extension of cPico
- Uses active objects as the unit of distribution
- Uses parent sharing to control mutable distributed state

Prototype-based Languages

- Classless object-oriented languages
- Ex-nihilo object construction and cloning
- Inheritance is either
  - Delegation-based: objects delegate incomprehensible messages to a ‘parent’
  - Concatenation-based: objects directly copy slots from a given ‘parent’ object

Self
Kevo
Agora
Obliq
Pic%

Parent Sharing in Pic%

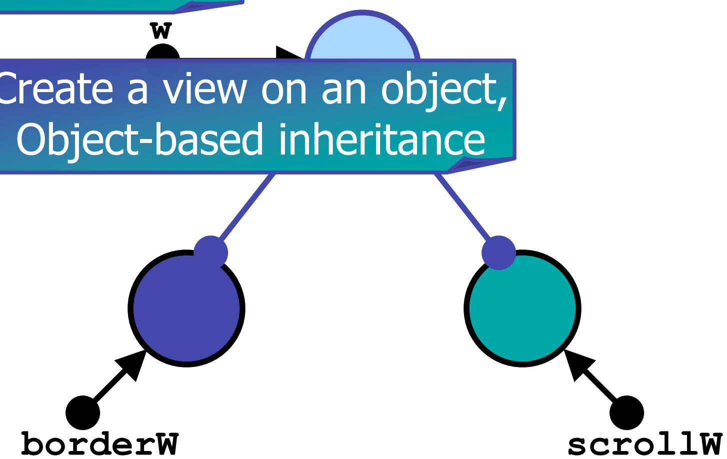
```
window(width, height) :: {
  minimized: false;
  draw() :: { … };
  asBorderedWindow(border) :: {
    draw() :: { .draw(); drawBorder(); };
    drawBorder() : { … };
    capture()
  };
  asScrollableWindow() :: {
    draw() :: { … };
    capture()
  };
  capture()
}
```

Overriding and super-sends

Object creation

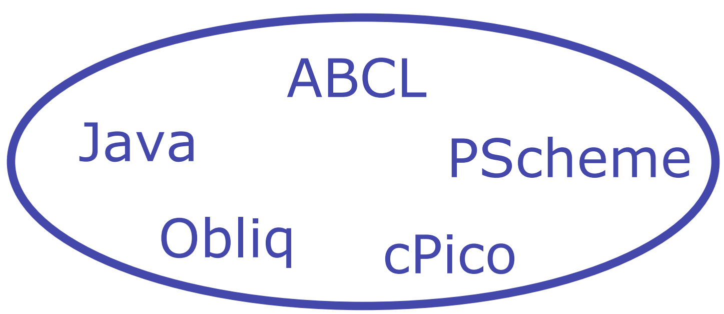
```
w: window(320, 240);
borderW:
w.asBorderedWindow(blue);
scrollW: w.asScrollableWindow();
```

Create a view on an object,
Object-based inheritance



Concurrent Programming Languages

- Languages able to cope with concurrent program execution
- Concurrency creation: threads, active objects, forking, ...
- Concurrency control: synchronization
  - Conditional Synchronization



Concurrent Programming Languages

- Concurrency Paradigm ‘design space’:

- The functional extreme
- No shared state
- Continuation-passing style
- Asynchronous Communication

- Shared state
- Controlled using parent sharing
- Synchronous and asynchronous communication
- Transparent synchronization

- The imperative extreme
- Shared mutable state
- Need for locks/semaphores/...
- Communication through shared data

cPico: a Concurrent Pic%

- An Integrative Approach (Briot et al., 1998):

Object Process	Message Active Object	Promises Shared Data
+ ———	+ ———	+ ———
Active Object	Inter-process communication	Synchronization

- Messages sent to active objects …
  - are handled asynchronously
  - are processed autonomously by receiver
  - are processed serially (“one at a time”)

Promises: Inter-object Synchronization

- Placeholders for the return value of an asynchronous message send
- Transparently become the return value
- Access to an “unfulfilled promise” blocks the accessor (“lazy synchronization”)
- Conditional synchronization achieved using “call-with-current-promise”
- Based upon futures:
  - Multilisp (Halstead, 1985)
  - ABCL/1 (Yonezawa et al., 1986)
  - Eiffel// (Caromel, 1989)

cPico: Design Issues

- Striving for simple consistent semantics
  - No active objects in delegation chains

	… to Active Objects	… to Passive Objects
Message Passing	Asynchronous	Synchronous
Delegation	Not Applicable	Synchronous

- Delegation versus synchronization problems
  - Return to static scope
  - Restricting visibility of variables
  - Distributed state more susceptible to deadlocks

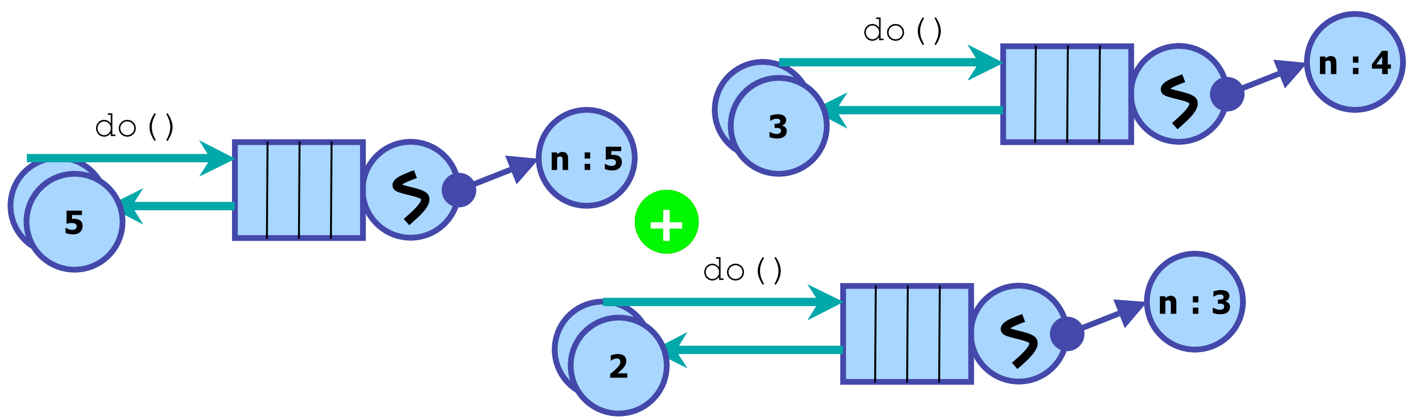
Example: Fibonacci

```
fibactor(n) :: {
  do() :: if (n<2,
              n,
              fibactor(n-1).do() + fibactor(n-2).do());
  activate()
}
fibactor(5).do()
```

Implicit Synchronization

Asynchronous Message Passing

Active Object creation



Facilitating Parent Sharing

- Scope Functions allow controlled access to a parent's variables:

Evaluation in…

```
this(exp)
```

Dynamic receiver

```
super(exp)
```

Static parent

```
cloning(exp)
```

Clone of object

atomic execution!

Distributed Programming Languages

- An application can be distributed across several machines linked by a network
- Introduces several issues:
  - Remote Method Invocation
  - Serialization of RMI parameters
  - Representation of Remote Objects
  - Partial Failure Handling
  - Object Lookup

Emerald
Borg
dPico
Argus
Obliq
dSelf

Why prototypes for distribution?

- Moving objects is more problematic in class-based languages:
  - Moving an object requires its class to ‘move along’
  - The transitive closure of the class’ superclasses must move along too
  - ‘moving along’ classes implies class replication
    - What about class consistency? Requires class versioning
    - What about static class variables? Requires replication management

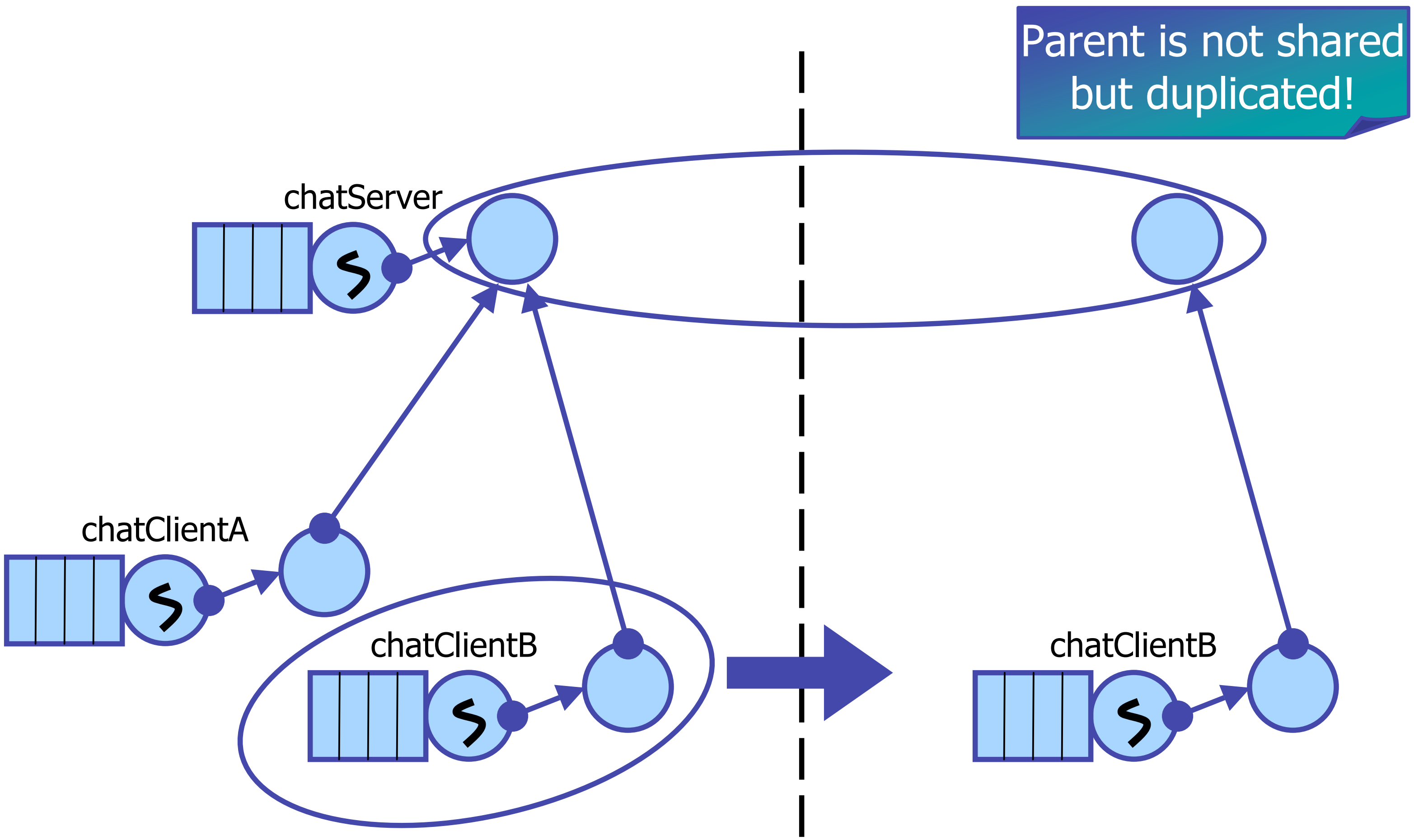
Why prototypes for distribution?

- Concatenation-based objects are dependency-free (no class or parent pointers)
- Delegation-based objects can share parents across virtual machine boundaries
  - This relation is explicit and thus transparent to the programmer, who remains in control
  - Shared parents can encapsulate distributed state and allow for broadcast communication (Dedecker et al., 2003; De Meuter et al., 2003a)
- Prototype-based languages have no trouble defining new 'types' of objects at run-time

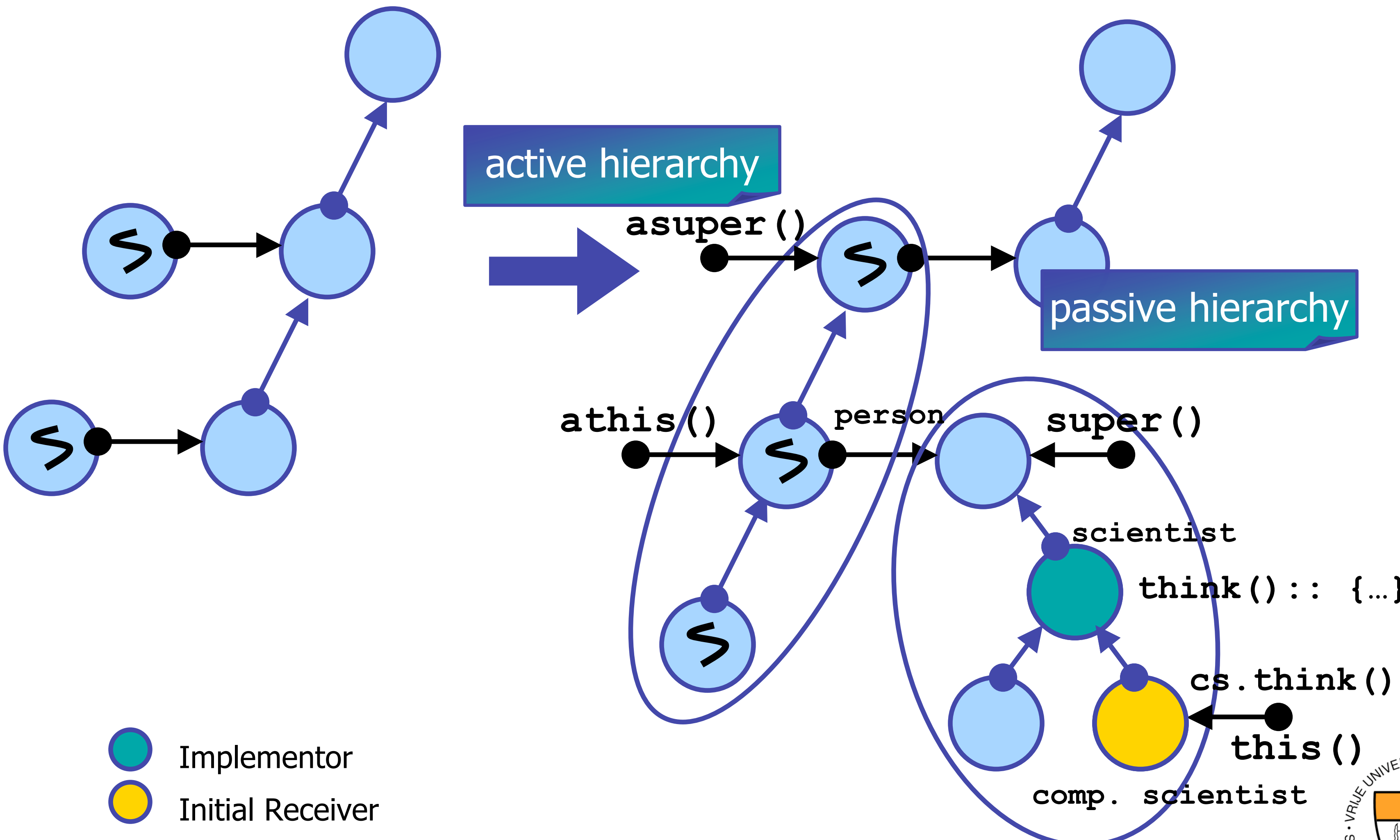
dPico: a Distributed Pic%

- Transparent Remote Active Objects
- Extension mechanism based on Agora (Introducing several *types* of methods)
- Active objects can 'publish' themselves in 'channels' accessible by remote VM's
- Very simple RMI parameter passing rules:
  - Active objects are always passed by reference
  - Any other dPico value is passed by copy
  - Remote references **always** point to **active** objects

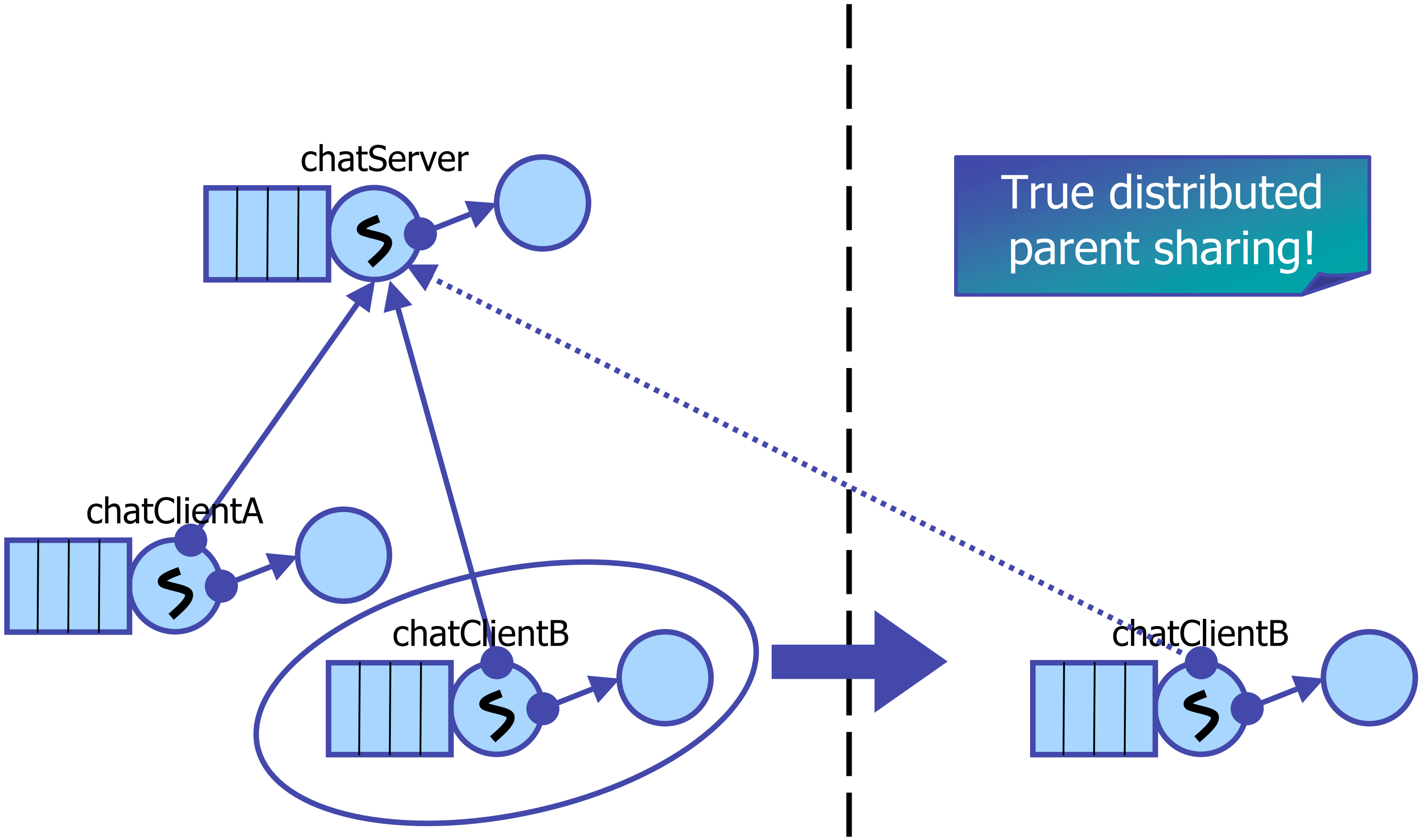
RMI Problem: distributed parent sharing?



Solution: restructuring active hierarchies



Solution: restructuring active hierarchies



Active Scope Functions

- Active counterpart of passive scope functions
- Operate asynchronously and immediately return a promise

Evaluation in…

```
athis(exp)
```

Dynamic active receiver

```
asuper(exp)
```

Static active parent

atomic execution!

Example: a Distributed Chat Client

transforms a regular method in a mixin method

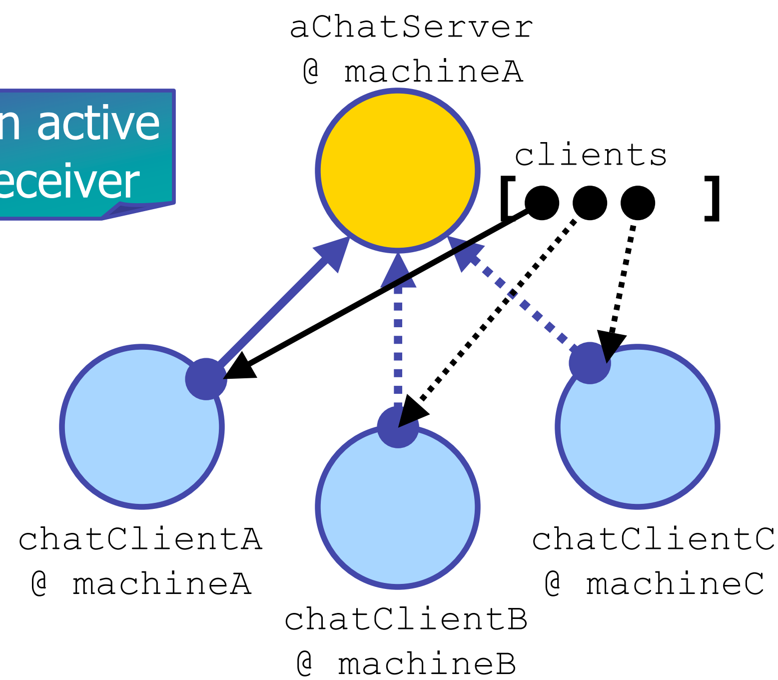
```
aview.chatServer(channel, maxClients) :: {
    clients[maxClients] : void;
    occupancy: 0;

    aview.registerClient(nam) :: {
        `create a new chat client`
    };

    sendMsg(msg) :: {
        `send msg to all clients`
    };
    athis().register(channel)
};
```

code executed in an active extension of the receiver

registers receiver in a channel



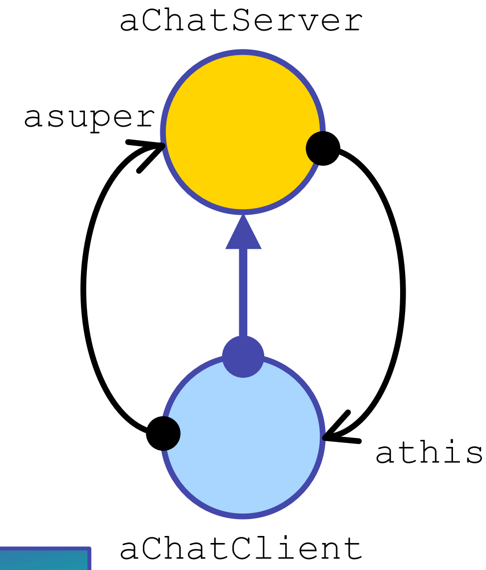
Example: a Distributed Chat Client

```
aview.chatServer(channel, maxClients) :: {
   ...
   aview.registerClient(nam) :: {
      receiveMsg(from,msg) :: display(from,": ",msg,eoln);
      asuper(
        if (occupancy = maxClients,
            error("Sorry, channel is full"),
            clients[occupancy := occupancy+1] := athis()) )
   };

   sendMsg(msg) :: {
        from: athis(nam);
        for(i:1, i <= occupancy, i:=i+1,
            clients[i].receiveMsg(from, msg));
   };
```

executed atomically and asynchronously in parent

asynchronous broadcast

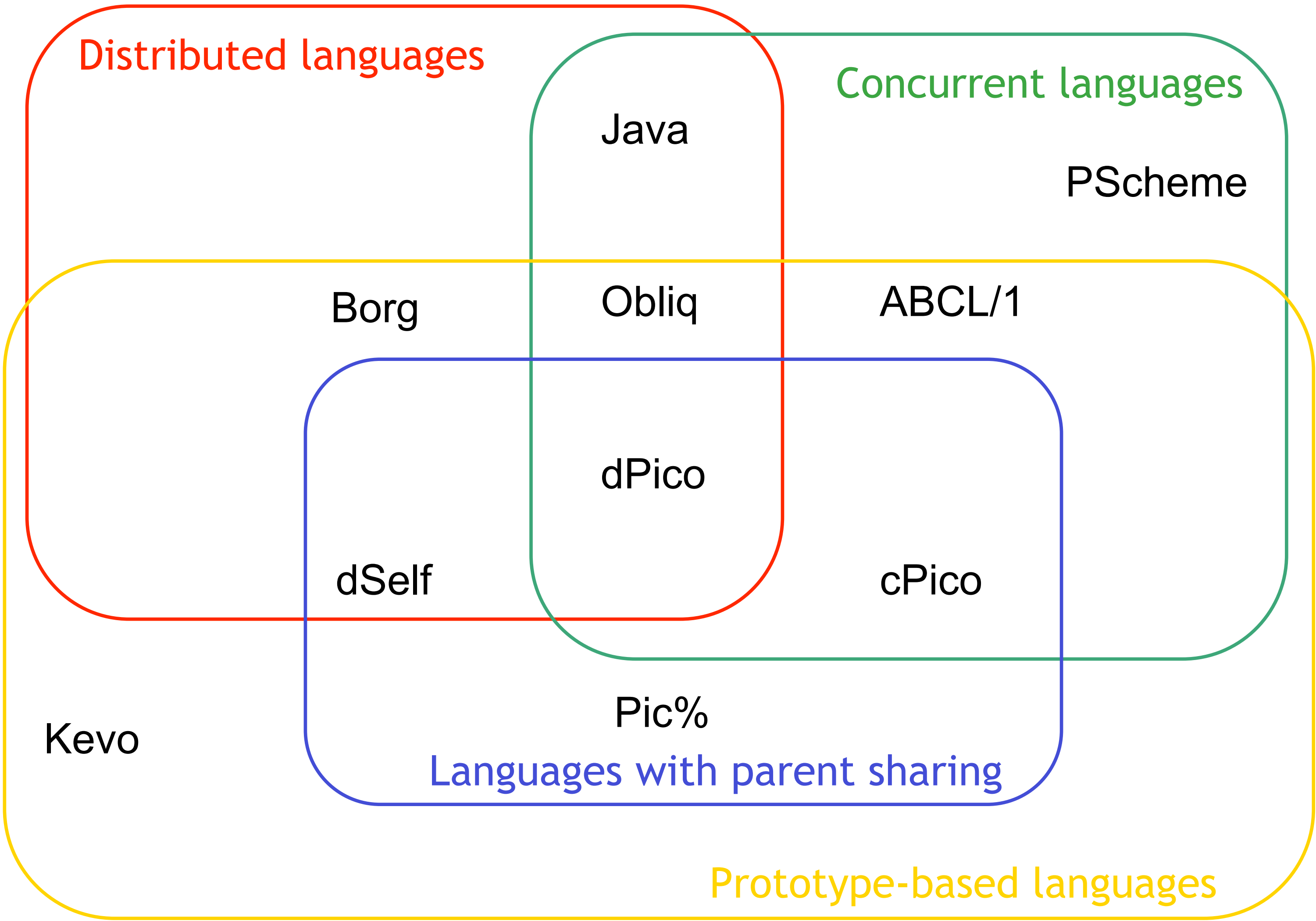


dPico: Strengths & Limitations

- Separation of active and passive entities leads to simple semantics
- Allows for true distributed object inheritance
- Primitive strong mobility due to first-class continuations
- RMI is expensive due to object graph serialization
- Message passing semantics are not totally location-independent

hotelObject.book(reservationObject)

Situating cPico and dPico



Future Work

- Using active objects to represent split objects
- Partial Failure Handling
  - Dealing with asynchronicity and promises
  - Modelling devices going ‘‘out of range’’
- Incorporating multivalues
  - Cloning family abstractions
  - Classification abstractions
  - Broadcast mechanisms
- Distributed Garbage Collection

Conclusions

- Design and implementation of
  - prototype-based concurrent language cPico
  - prototype-based distributed language dPico
- Parent sharing in a distributed setting
  - Scope functions allow controlled access to shared distributed state
  - Sharing of state without sacrificing encapsulation
  - Separation of active and passive hierarchies ensures clean semantics
- Basis for future language engineering research in the field of AmI