Communicating Event Loops

An exploration in Javascript

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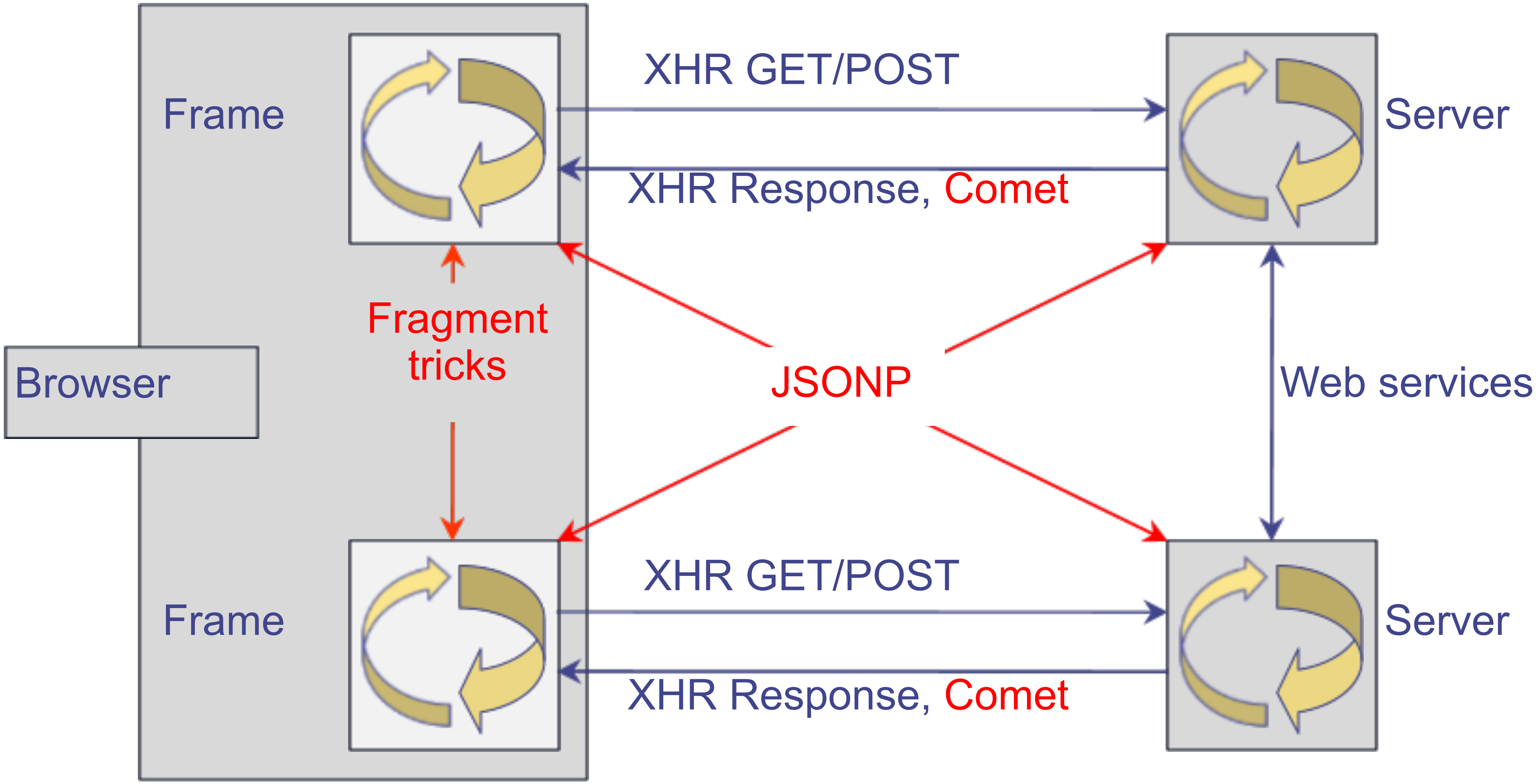
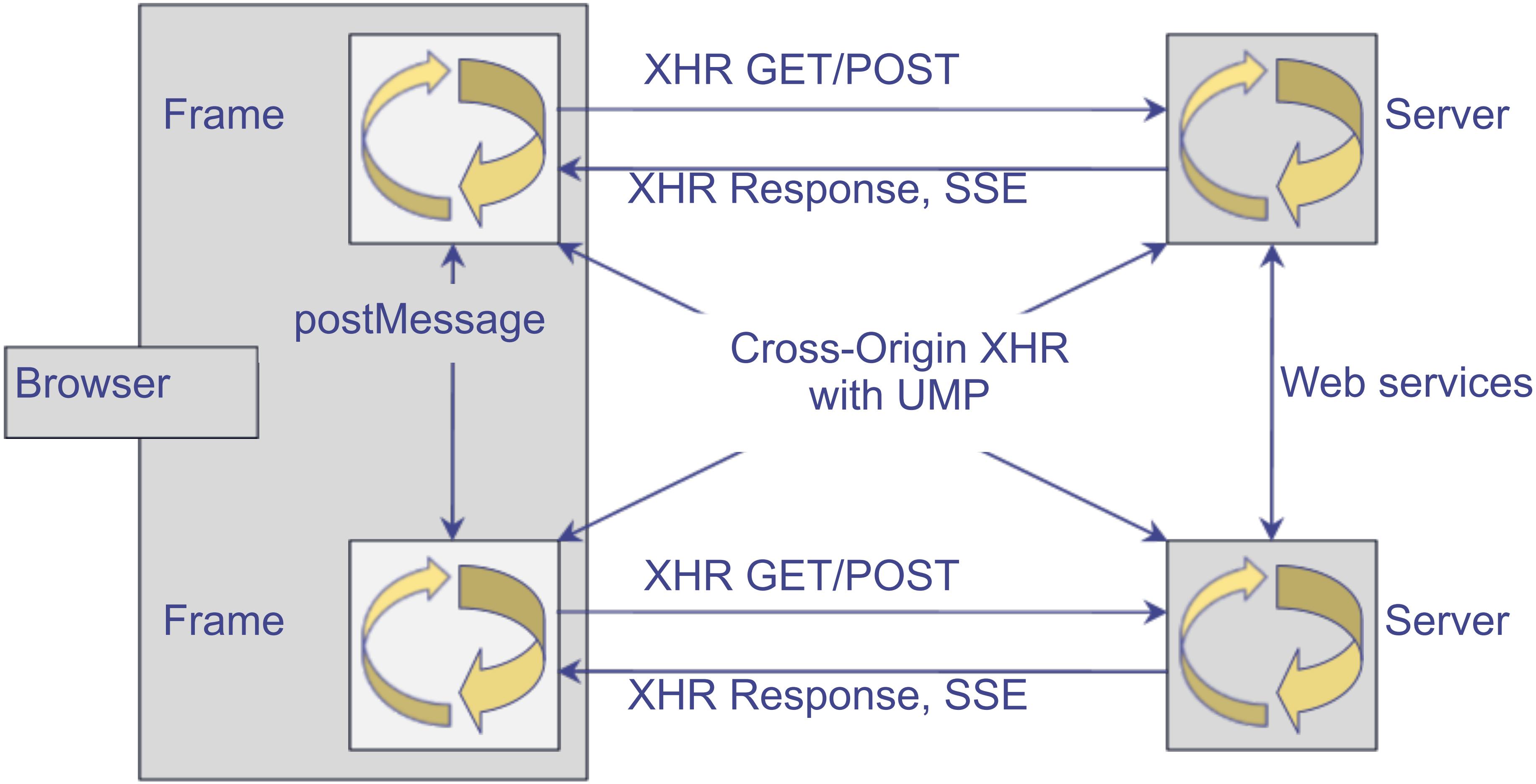
Kludging Towards Distributed Objects



A Web of Distributed Objects



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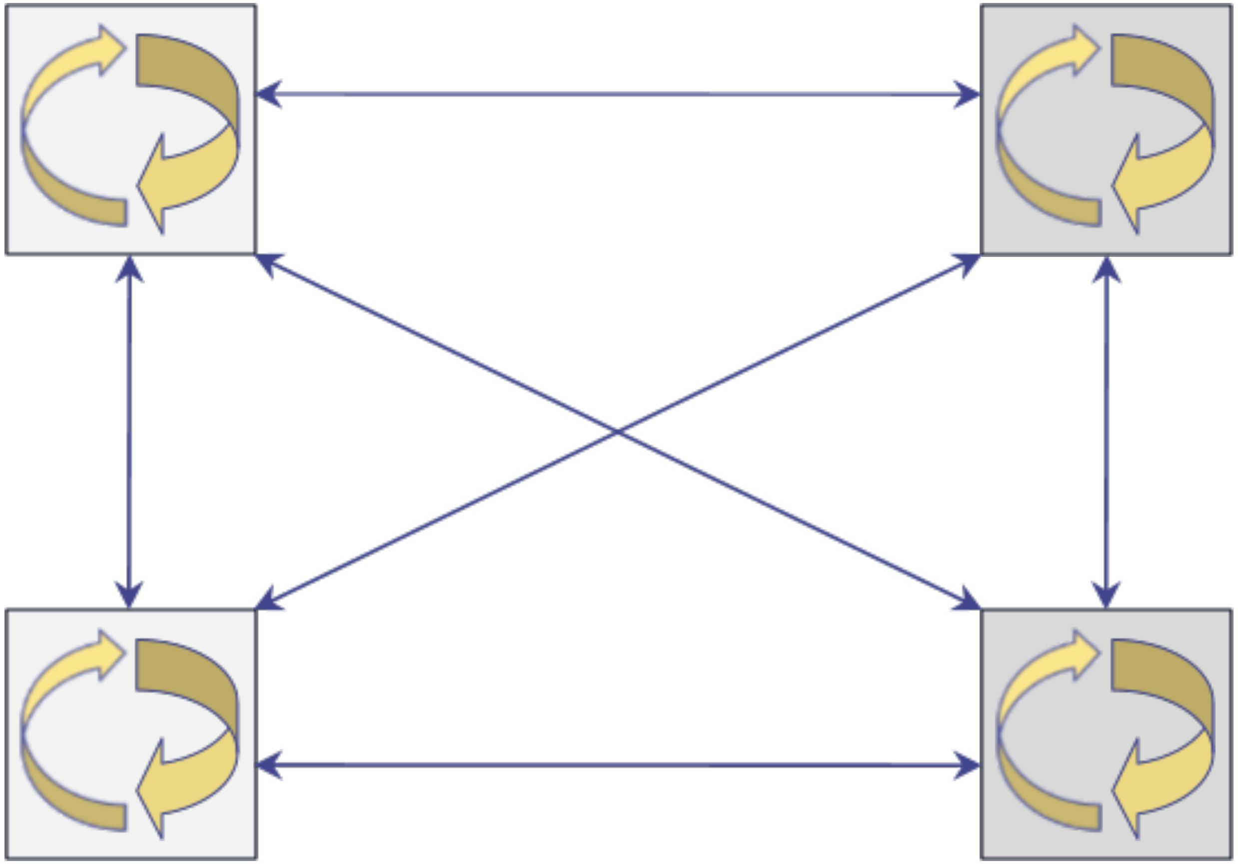
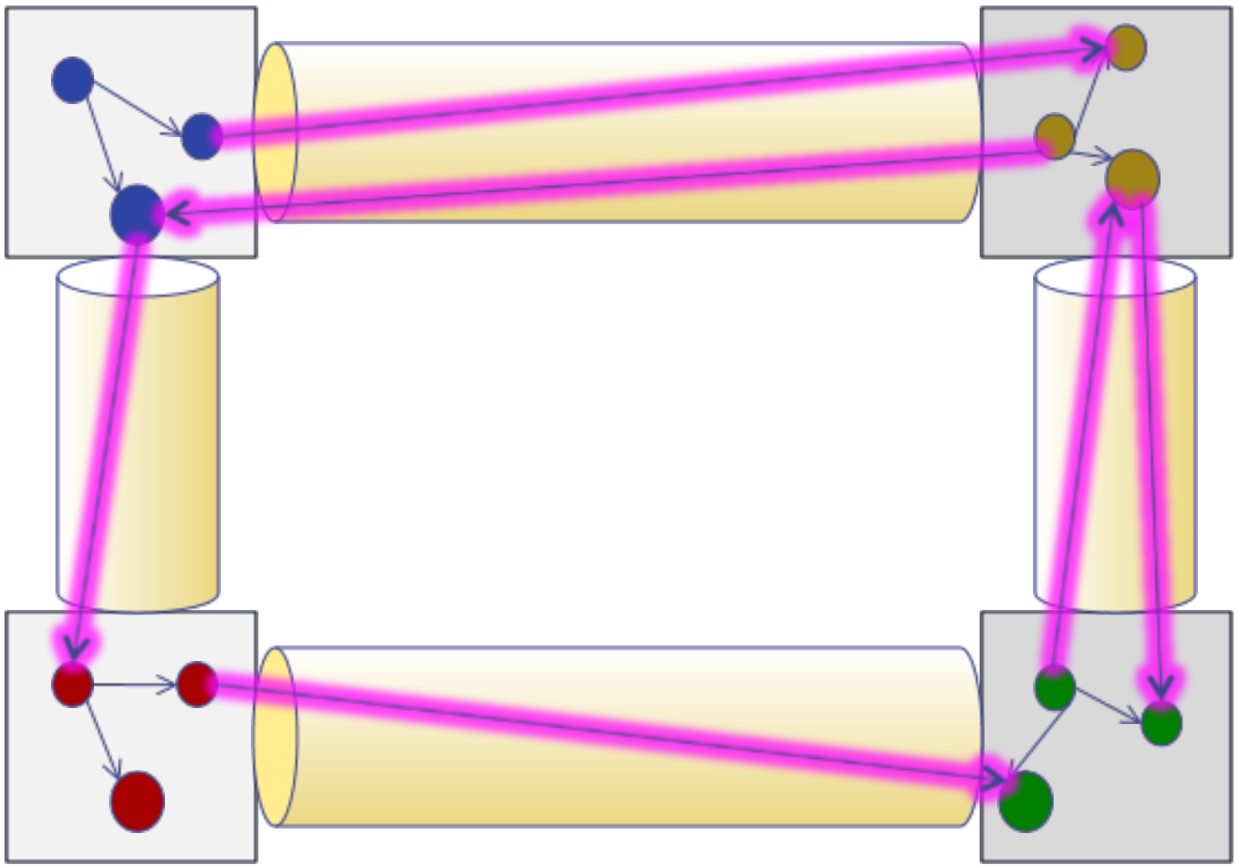
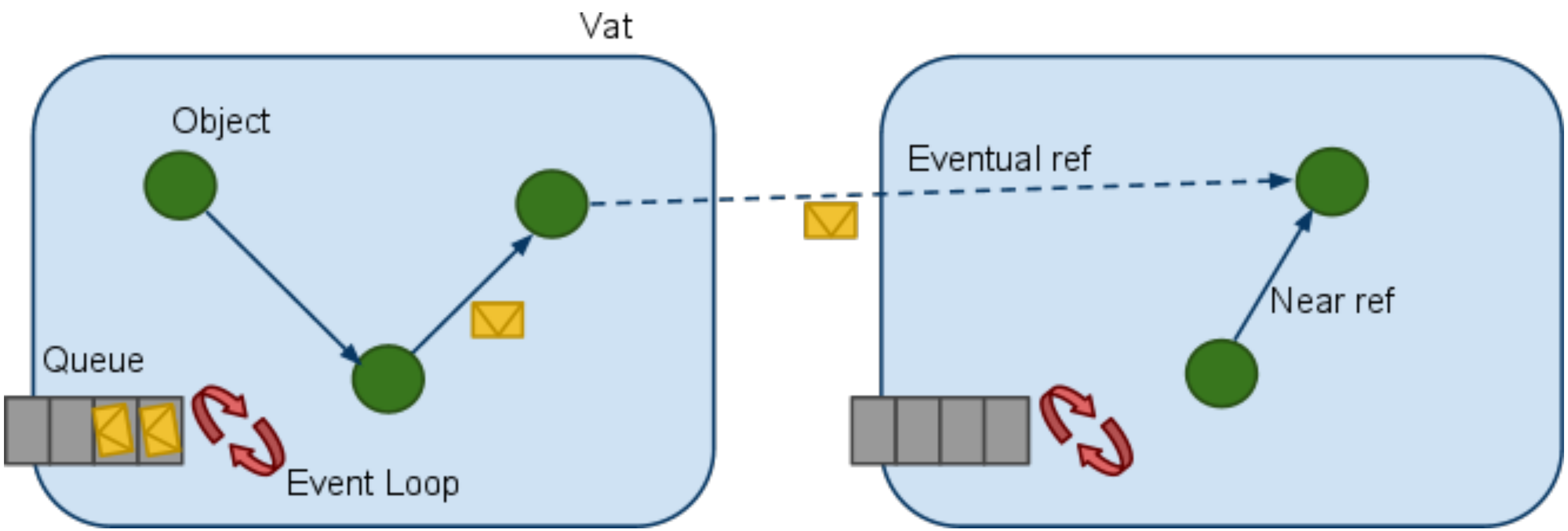


Mobile messages, code, objects

A Web of Distributed Objects



Communicating Event Loops

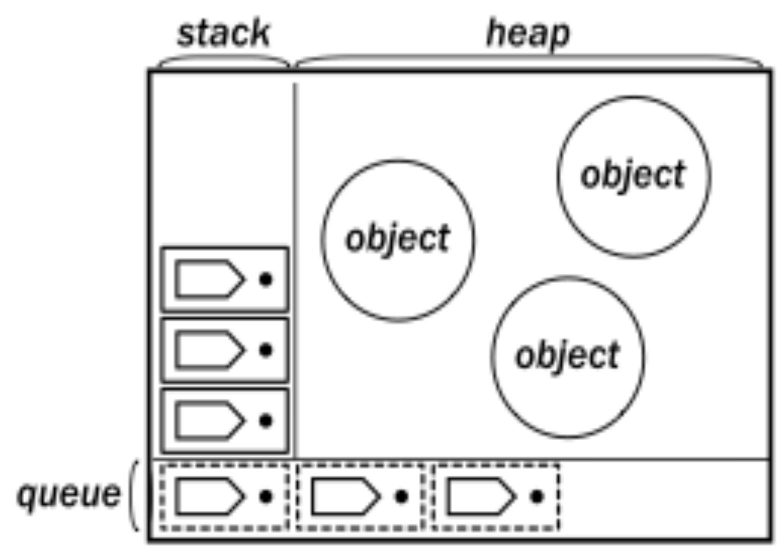


Events = asynchronous messages

Event handlers = methods

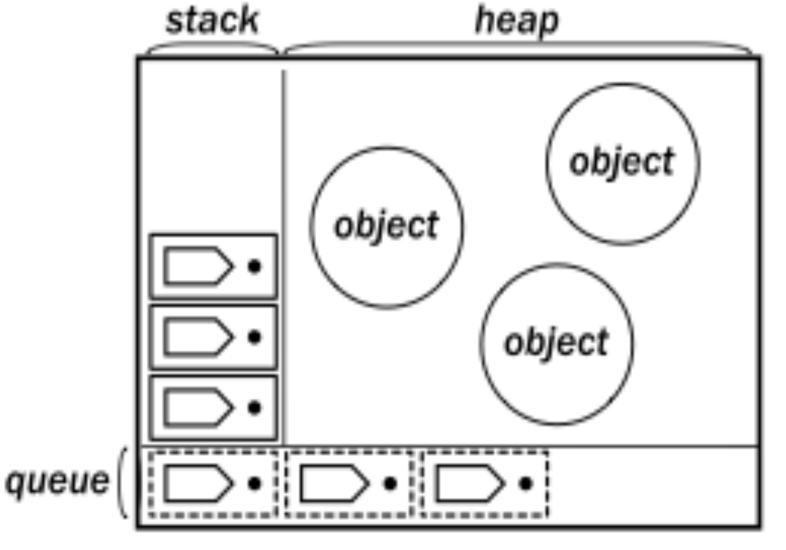
Vats

- A vat is a container for objects, consisting of:
  - A heap of objects
  - A LIFO call stack of method invocations
  - A FIFO queue of pending message deliveries
  - Incoming and outgoing references (see later)



Turns

- A vat processes messages in its queue sequentially
- Each such message triggers a method invocation on a local object
- This method is run to completion
  - Determines a single execution "turn"
  - No preemption, no interleaving
- Computation proceeds
  - From stack top to bottom
  - From queue left to right



Properties

- Within a vat: plain sequential OOP
- Between vats: strictly asynchronous messaging
  - no conventional deadlocks
  - hides latency
- Explicit unit of interleaving (*turns*)
  - turns run to completion: no races on vat-local state
  - easy to add new events without breaking existing code
  - control flow across turns "inverted"
- Explicit locality boundaries (*vats*)
  - no synchronously accessible shared state
  - easy to add new vats without breaking existing vats
  - partitioning state across vats requires consideration
- Non-determinism is restricted to message arrival order

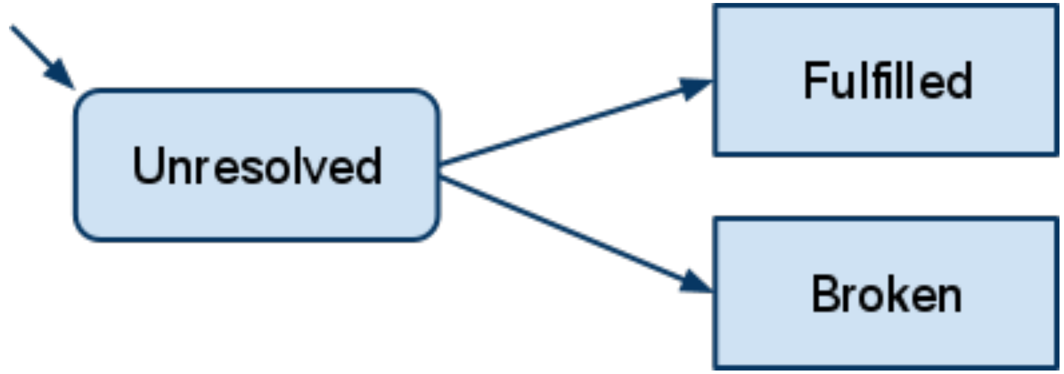
Immediate call vs. eventual send

```
o.m(1,2,3); // immediate call

o ! m(1,2,3); // eventual send
```

Promise

- A placeholder for an asynchronous value
- Either resolved with a value or broken with an exception

let *p* = o ! m(x);



Example

```
let calculator = {
  add: function(x, y) { return x + y; },
  ...
};

let sumP = calculator ! add(3, 5);
// sumP resolves to 8 in a later turn
```

Promise

It is *not* possible to block a vat to await the value of a promise.

```
let p = o ! m(x);
p.get();
```

When (control-flow synchronization)

How to get at the resolved value?

```
Q.when(expr, function(v) {
  // "callback"
}, function(err) {
  // "errback"
})
```

- *expr* may evaluate to a promise
- v will be bound to the promise's fulfilled value
- callback or errback *guaranteed* only to execute in a later turn
- *either* the callback *or* the errback triggers at most once

Example

```
let calculator = {
  add: function(x, y) { return x + y; },
  ...
};

Q.when(calculator ! add(3, 5), function(sum) {
  console.log(sum); // logs 8 in a later turn
})
```

Promise chaining
(dataflow synchronization)

Dependent promises form a dataflow network

```
let p1 = o ! m(x);
let p2 = p1 ! n(y); // p2 depends on p1
```

```
let o2 = {
  f: function() { let p3 = o ! m(x); return p3; }
};
let p4 = o2 ! f(); // p4 depends on p3
```

Promise chaining
(dataflow synchronization)

- when-expression evaluates to a promise itself

```
// p2 depends on p1
let p2 = Q.when(p1, function(x) {
  return x + 1;
}, function(err) {
  throw err;
});
```

Q.when reconciles asynchronous programming with functional programming style.

Possible syntactic sugar

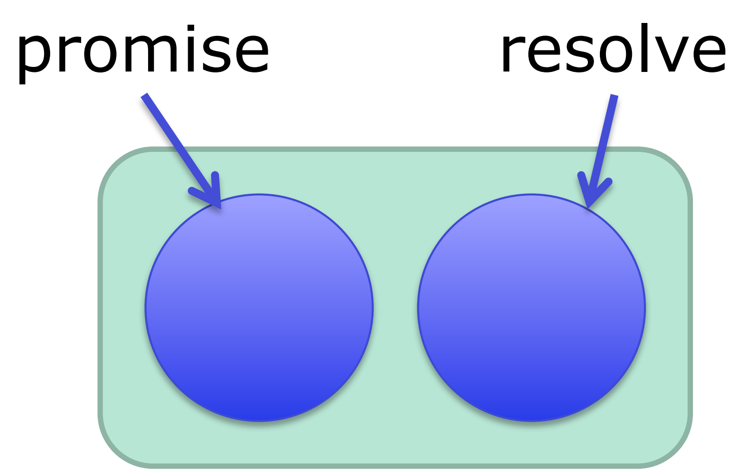
await = shallow continuation + Q.when

```
let p2 = function() {
  try {
    return (await p1) + 1;
  } catch (err) {
    throw err;
  }
})();
```

Explicit promise creation

Required when promise resolution should be postponed based on conditions other than message passing

```
function delay(millis, answer = undefined) {
  let {promise, resolve} = Q.defer();
  setTimeout(function() {
    resolve(answer);
  }, millis);
  return promise;
}
```



Broken promise contagion

A promise that depends on a broken promise itself becomes broken, with the same exception

```
let o = {
  m: function() { throw "an exception"; }
};

Q.when(o ! m(x) ! n(y), function(x) {
   // ...
}, function(err) {
   // will trigger with err = "an exception"
}
```

Asynchrony contagion

Asynchrony cannot be hidden by functional abstraction

```
function f() {
  ...
  return v;
}


function g() {
  /*A*/
  let val = f();
  /*B*/
  return v2;
}
```

```
function f() {
  ...
  return p;
}

function g() {
  /*A*/
  let p2 = Q.when(f(),
    function(val) {
      /*B*/
    });
  return p2;
}
```

Asynchrony contagion

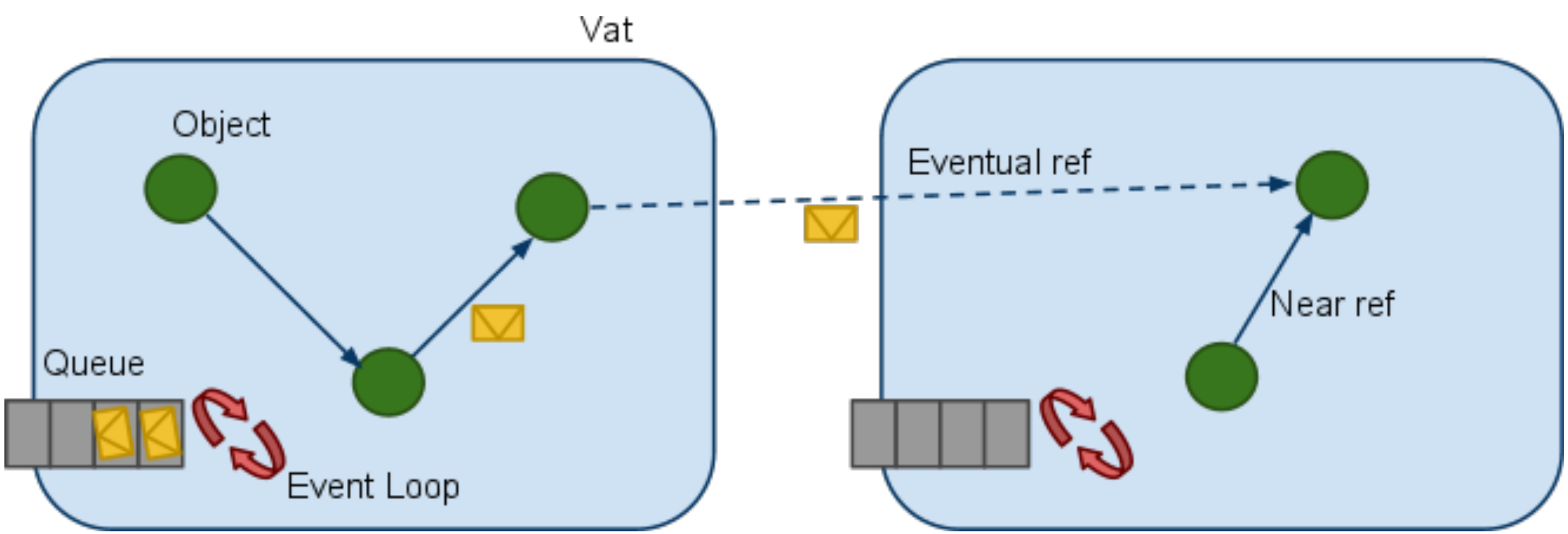
Asynchrony cannot be hidden by functional abstraction

```
function f() {
  ...
  return v;
}

function g() {
  /*A*/
  let val = f();
  /*B*/
  return v2;
}
```

```
function f() {
  ...
  return p;
}

function g() {
  /*A*/
  let val = await f();
  /*B*/
  return v2;
}
```

Communicating event loops

- Objects can be spread across multiple vats
  - May or may not be distributed across multiple machines
  - *Near* vs *Far* references
  - Far reference points to an *individual* object within another vat, *not* to the vat as a whole (!)



Distributed parameter passing semantics

- By default, objects are passed "by far reference"
  - invoked method is given a far reference to the object
- Primitive values are passed by copy
- Can easily pass objects "by copy" by serializing them into a JSON string

```
// in vat A
let arg = {...};
obj ! m(arg);
```

```
// in vat B
function m(param) {
  // param is far
}
```

RESTful remote invocations

Assume o is a far reference, pointing to a vat serving the URL https://...

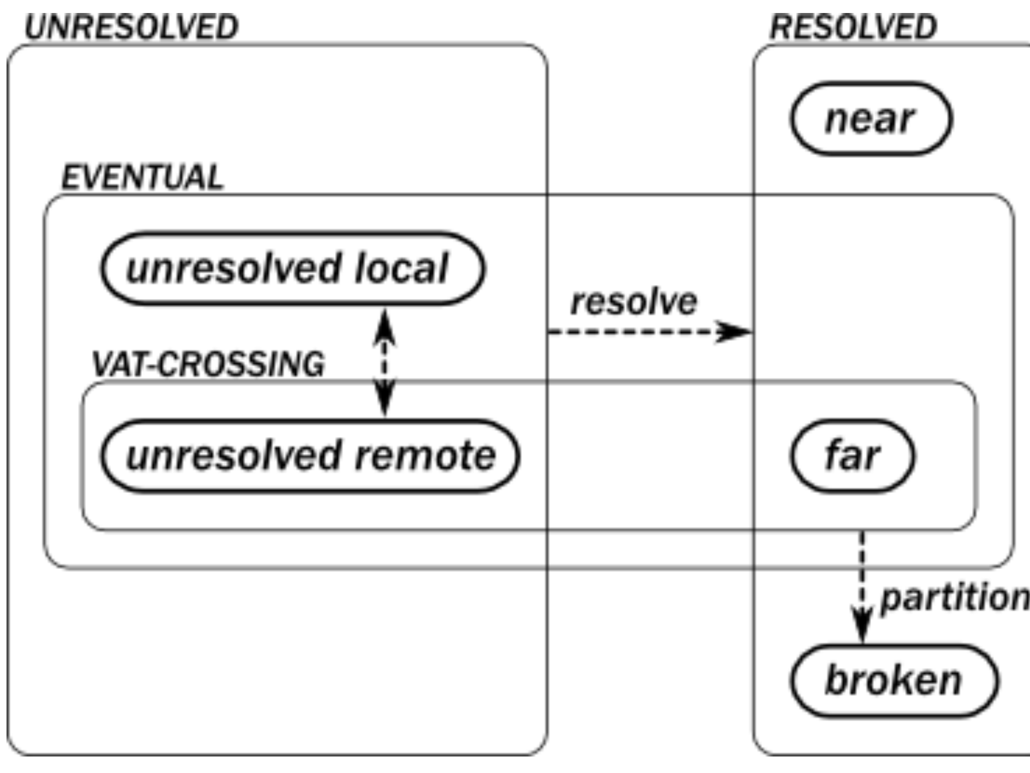
```
let p = o ! m;          GET https://...?q=m
let p = o ! m(x);       POST https://...?q=m body
                          where
                            body = JSON.stringify(x, ...)
```

Eventual references

- Promises and far references are *eventual*
- An eventual reference enforces eventual (asynchronous) access to its target

	Near reference	Eventual reference
Immediate call o.m()	Method invocation	Error
Eventual send o ! m()	Enqueue message in own vat	Enqueue message in target's vat

State diagram of a promise, revisited



Failures

What if the target of an eventual reference becomes disconnected (e.g. due to a network partition)?

Model allows for different failure semantics. For example:

- E: partial failure permanently breaks the reference
- AmbientTalk: messages are buffered on disconnected refs, may reconnect, may also "expire" ("leased" references)
- Waterken: partial failures never break references

What model to support in Javascript?

Experimental feature: where

- Javascript scripts are routinely exchanged between machines (mobile code)
- Why not provide direct linguistic support for this idiom?

```
let local = {...};
Q.when(o!m(), function(v) {
  // v is eventual
  // local is near
}, function (err) {
  // local is near
});
```

```
let local = {...};
Q.where(o!m(), function(v) {
  // v is near
  // local is eventual
}, function (err) {
  // local is near
});
```

Example: MapReduce Lite

```
// initValue = value of T'
// elemPs    = array of promise<T>
// mapper   = closed, mobile function T -> T'
// reducer  = function T' x T' -> T'
// returns promise<T'> | T'
function mapReduce(initValue, elemPs, mapper, reducer) {
    let countDown = elemPs.length;
    if (countDown === 0) { return initValue; }
    let result = initValue;
    let {promise, resolve} = Q.defer();

    elemPs.forEach(function(elemP) {
      let mappedP = Q.where(elemP, mapper);
      Q.when(mappedP, function(mapped) {
        result = reducer(result, mapped);
        if (--countDown === 0) { resolve(result); }
      }, resolve);
    });
    return promise;
}
```

History

Hewitt's Actor model

Liskov's Argus: guardians ~ vats, (blocking) promises

E: Original-E, Joule, Vulcan

AmbientTalk: E, Yonezawa's ABCL

Communicating Event Loops (Recap)

- Concurrency model that:
  - Blends well with objects and messages
  - Scales to distributed programs
- Explicit locality boundaries (*vats*)
  - Within a vat: plain sequential OOP
  - Between vats: strictly asynchronous messaging
- Explicit unit of interleaving (*turns*)
  - Promises stitch turns together
  - Reconcile asynchronous and functional programming