

Arrows in Commercial Web Applications

Eric Fritz Jose Antony Tian Zhao

University of Wisconsin - Milwaukee

Research History

Directing JavaScript with Arrows

Khoo Yit Phang, Michael Hicks, Jeffrey S. Foster, and Vibha Sazawal.
5th Symposium on Dynamic Languages, 2009.

Research History

Directing JavaScript with Arrows

Khoo Yit Phang, Michael Hicks, Jeffrey S. Foster, and Vibha Sazawal.
5th Symposium on Dynamic Languages, 2009.

Inferring Types of Asynchronous Arrows in JavaScript

Eric Fritz and Tian Zhao.

Reactive and Event-based Languages and Systems, 2015.

Research History

Directing JavaScript with Arrows

Khoo Yit Phang, Michael Hicks, Jeffrey S. Foster, and Vibha Sazawal.
5th Symposium on Dynamic Languages, 2009.

Inferring Types of Asynchronous Arrows in JavaScript

Eric Fritz and Tian Zhao.

Reactive and Event-based Languages and Systems, 2015.

Typing and Semantics of Asynchronous Arrows in JavaScript

Eric Fritz and Tian Zhao.

In Review, 2016.

Research History

Directing JavaScript with Arrows

Khoo Yit Phang, Michael Hicks, Jeffrey S. Foster, and Vibha Sazawal.
5th Symposium on Dynamic Languages, 2009.

Inferring Types of Asynchronous Arrows in JavaScript

Eric Fritz and Tian Zhao.

Reactive and Event-based Languages and Systems, 2015.

Typing and Semantics of Asynchronous Arrows in JavaScript

Eric Fritz and Tian Zhao.

In Review, 2016.

Arrows in Commercial Web Applications

Eric Fritz, Jose Antony, and Tian Zhao.

HotWeb, 2016.

Example Application - Inventory Search

[Prev](#) · Displaying 21-24 of 24 · [Next](#)

ID	Name	Category	Subcategory	Price / Unit	Margin
223	Rush Hierlooms Collection 1" Thick Stackable Bookcases	Furniture	Bookcases	170.98	0.66
224	Rush Hierlooms Collection Rich Wood Bookcases	Furniture	Bookcases	160.98	0.72
230	Safco Value Mate Steel Bookcase, Baked Enamel Finish on Steel, Black	Furniture	Bookcases	70.98	0
231	Sauder Camden County Barrister Bookcase, Planked Cherry Finish	Furniture	Bookcases	120.98	0.71

Example Application - Inventory Search

<input type="text" value="bookcase"/>		Prev · Displaying 21-24 of 24 · Next			
ID	Name	Category	Subcategory	Price / Unit	Margin
223	Rush Hierlooms Collection 1" Thick Stackable Bookcases	Furniture	Bookcases	170.98	0.66
224	Rush Hierlooms Collection Rich Wood Bookcases	Furniture	Bookcases	160.98	0.72
230	Safco Value Mate Steel Bookcase, Baked Enamel Finish on Steel, Black	Furniture	Bookcases	70.98	0
231	Sauder Camden County Barrister Bookcase, Planked Cherry Finish	Furniture	Bookcases	120.98	0.71

Requirements:

Filter displayed results by name and category

Paginate results when filtered set is > 50 items

Example Application - Inventory Search

Prev · Displaying 21-24 of 24 · Next

ID	Name	Category	Subcategory	Price / Unit	Margin
223	Rush Hierlooms Collection 1" Thick Stackable Bookcases	Furniture	Bookcases	170.98	0.66
224	Rush Hierlooms Collection Rich Wood Bookcases	Furniture	Bookcases	160.98	0.72
230	Safco Value Mate Steel Bookcase, Baked Enamel Finish on Steel, Black	Furniture	Bookcases	70.98	0
231	Sauder Camden County Barrister Bookcase, Planked Cherry Finish	Furniture	Bookcases	120.98	0.71

Requirements:

Filter displayed results by name and category

Paginate results when filtered set is > 50 items

Performance Optimizations:

Cache server results for same query/page

Attempt to pre-fetch the next page of results

Don't make a remote request while the user is typing

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```

main

Call Stack



Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```

main

Call Stack



keyup \mapsto *closure₁*

Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```



Call Stack

keyup \mapsto *closure₁*

Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

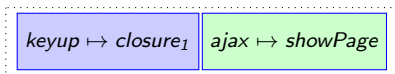
function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```



Call Stack



Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```

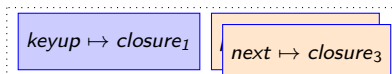


Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```



Call Stack



Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```



Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {
  $.ajax({ 'url': makeURL(query, page), 'success': handler });
}

function showPage(resp) {
  const pageTo = (page) => () => {
    $('#prev, #next').unbind('click');
    call(resp.query, page, showPage);
  };

  displayTable(resp);
  $('#prev').one('click', pageTo(resp.prev));
  $('#next').one('click', pageTo(resp.next));
}

$('#filter').keyup((ev) => {
  $('#prev, #next').unbind('click');
  call($(ev.target).val(), 1, showPage);
});
```

closure₂



keyup \mapsto *closure₁*

prev \mapsto *closure₂*

Call Stack

Event Queue

Sequencing Filtering + Paging (Using Callbacks)

```
function call(query, page, handler) {  
  $.ajax({ 'url': makeURL(query, page), 'success': handler });  
}  
  
function showPage(resp) {  
  const pageTo = (page) => () => {  
    $('#prev, #next').unbind('click');  
    call(resp.query, page, showPage);  
  };  
  
  displayTable(resp);  
  $('#prev').one('click', pageTo(resp.prev));  
  $('#next').one('click', pageTo(resp.next));  
}  
  
$('#filter').keyup((ev) => {  
  $('#prev, #next').unbind('click');  
  call($(ev.target).val(), 1, showPage);  
});
```



Callbacks - The Problems

Lose flow of (synchronous) code

Callbacks - The Problems

Lose flow of (synchronous) code
Event registration/de-registration is ad-hoc

Callbacks - The Problems

Lose flow of (synchronous) code
Event registration/de-registration is ad-hoc
Lose imperative exception semantics

```
try {  
  User.findOne({name: 'Eric'}, (err, obj) => {  
    if (err != null) { throw err; }  
    else if (obj == null) { throw new Error('Not Found'); }  
    else { /* ... */ }  
  });  
} catch (err) {  
  /* ... */  
}
```

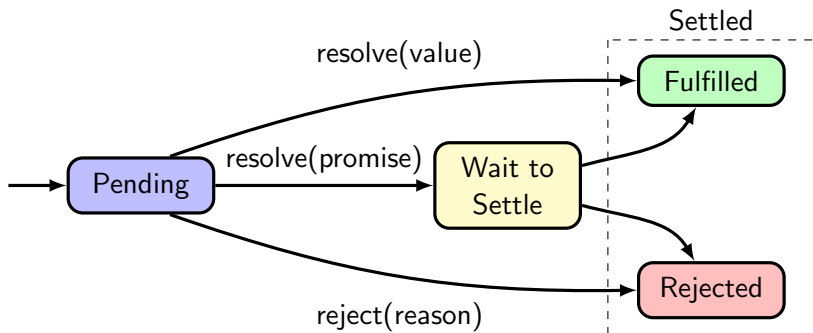
Callbacks - The Problems

Lose flow of (synchronous) code
Event registration/de-registration is ad-hoc
Lose imperative exception semantics

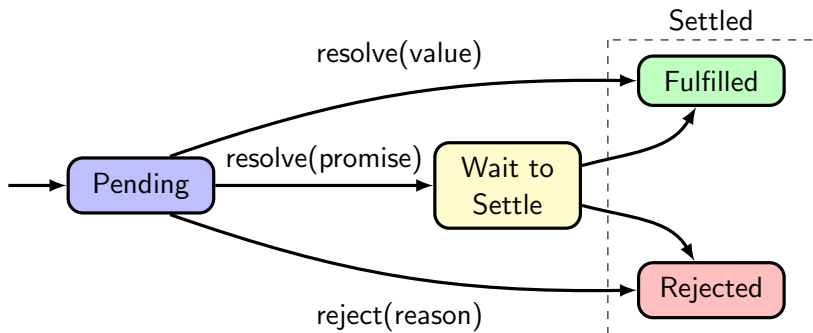
```
try {  
  User.findOne({name: 'Eric'}, (err, obj) => {  
    if (err != null) { throw err; }  
    else if (obj == null) { throw new Error('Not Found'); }  
    else { /* ... */ }  
  });  
} catch (err) {  
  /* ... */  
}
```

20% of function calls provide a callback
72% of callbacks are asynchronous
48% of callbacks are anonymous

Promises – A Better Abstraction

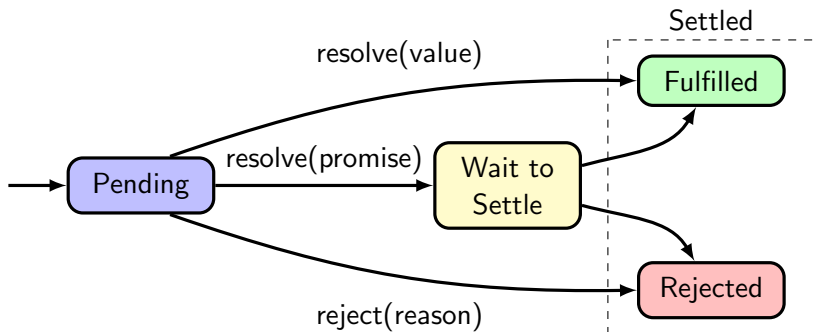


Promises – A Better Abstraction



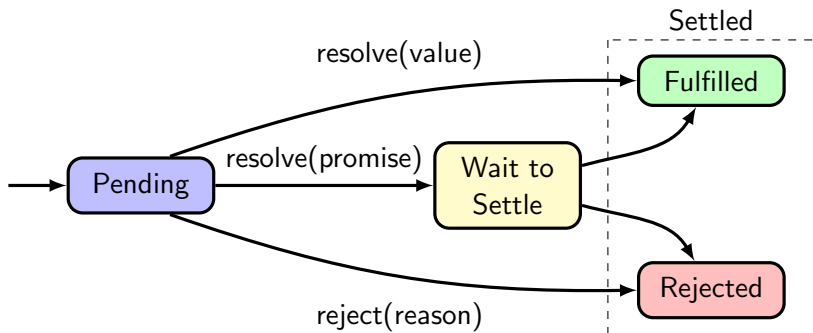
```
var promise = new Promise((resolve, reject) => {  
  conn.query('SELECT * from items', (err, row) => {  
    if (!!err) resolve(row);  
    else      reject(err);  
  });  
});
```

Promises – A Better Abstraction



```
var promise = new Promise((resolve, reject) => {  
  conn.query('SELECT * from items', (err, row) => {  
    if (!!err) resolve(row);  
    else reject(err);  
  });  
});
```

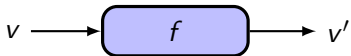
Promises – A Better Abstraction



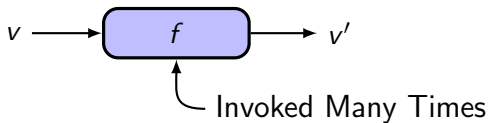
```
var promise = new Promise((resolve, reject) => {  
  conn.query('SELECT * from items', (err, row) => {  
    if (!!err) reject(err);  
    else      resolve(row);  
  });  
});
```

```
promise.then(onSuccess);  
promise.then(onSuccess, onError);  
promise.then(onSuccess).catch(onError);
```

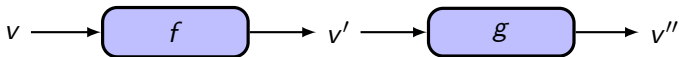
Arrows – Attacking the Abstraction Differently



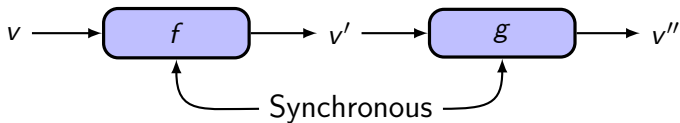
Arrows – Attacking the Abstraction Differently



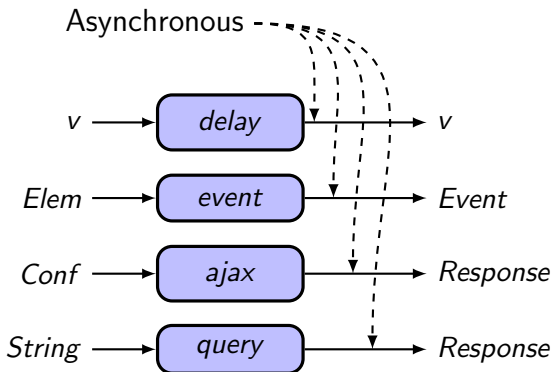
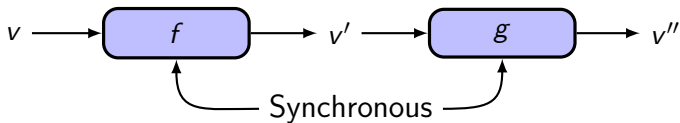
Arrows – Attacking the Abstraction Differently



Arrows – Attacking the Abstraction Differently



Arrows – Attacking the Abstraction Differently



Arrows - Async Machine Composition

```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
])));

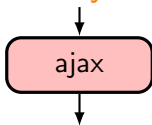
let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
])).onkeyup('#filter'));

filter.run();
```

Composition Time {

Execution Time {

Arrows - Async Machine Composition

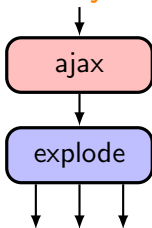


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
]));

let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```

Arrows - Async Machine Composition

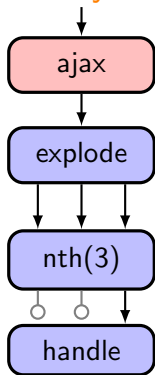


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
])));

let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```

Arrows - Async Machine Composition

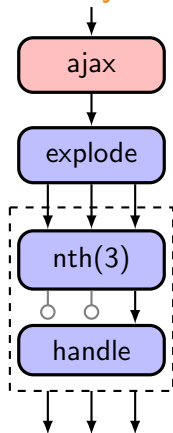


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
]));
```

```
let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```


Arrows - Async Machine Composition

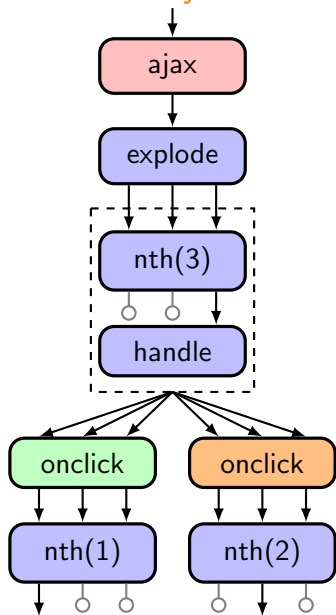


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
])));

let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```

Arrows - Async Machine Composition

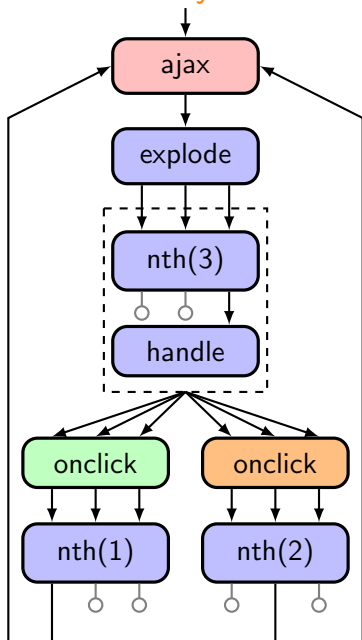


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
]));
```

```
let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```

Arrows - Async Machine Composition

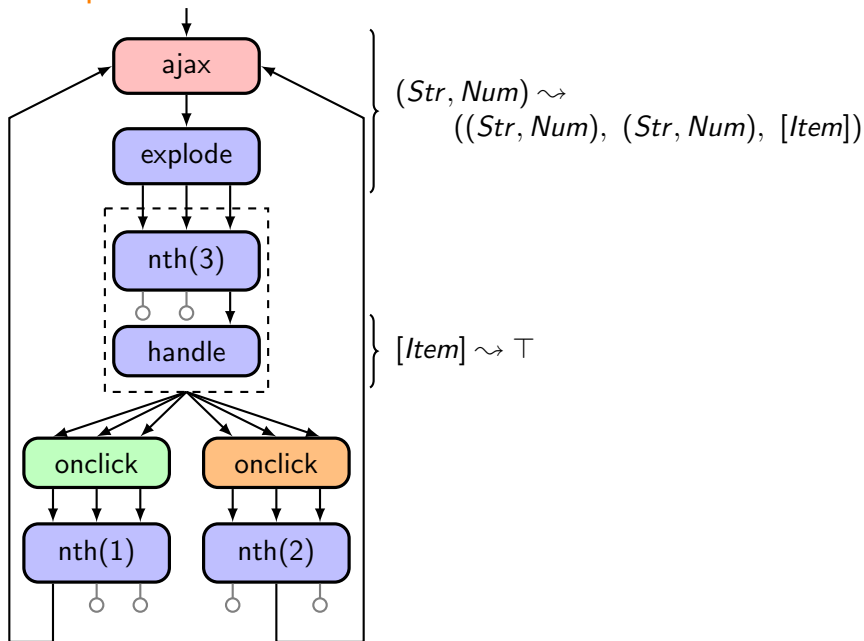


```
let page = Arrow.fix(a => Arrow.seq([
  ajax,
  explode,
  Arrow.seq([
    new NthArrow(3),
    handle
  ]).remember(),
  Arrow.any([
    new NthArrow(1).onclick('#prev'),
    new NthArrow(2).onclick('#next'),
  ]),
  a,
])).run();
```

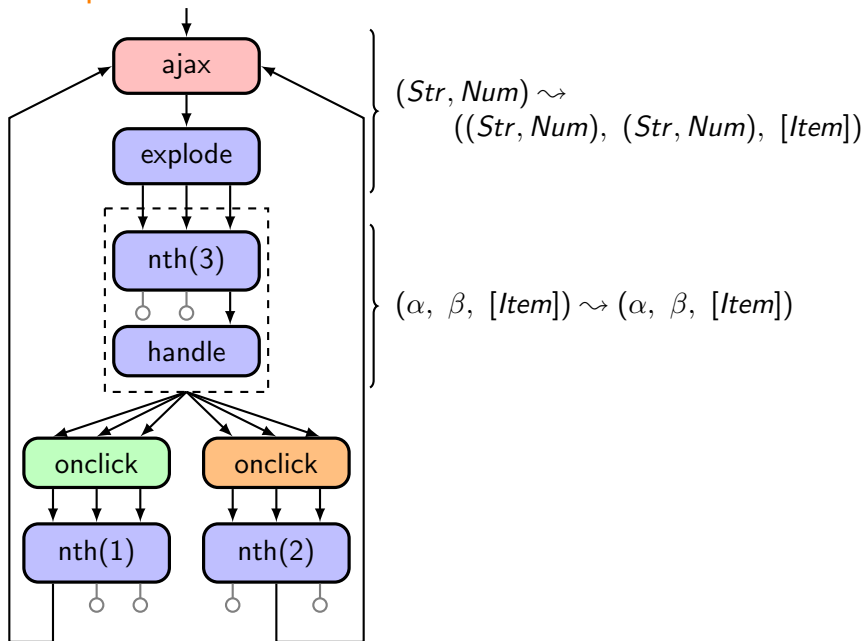
```
let filter = Arrow.fix(a => Arrow.any([
  Arrow.seq([
    getQueryAndPage,
    page
  ]).noemit(),
  a
]).onkeyup('#filter'));

filter.run();
```

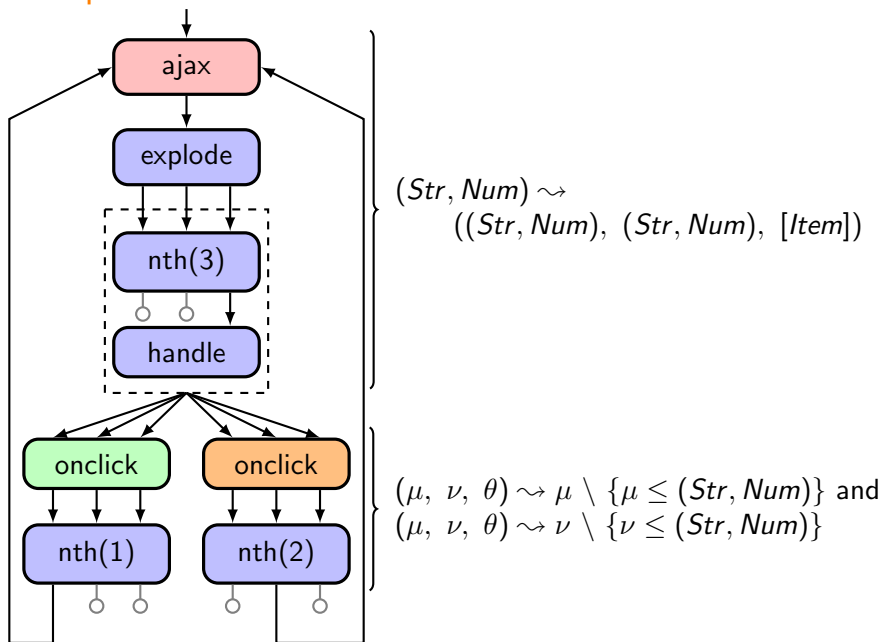
Composition-Time Inference



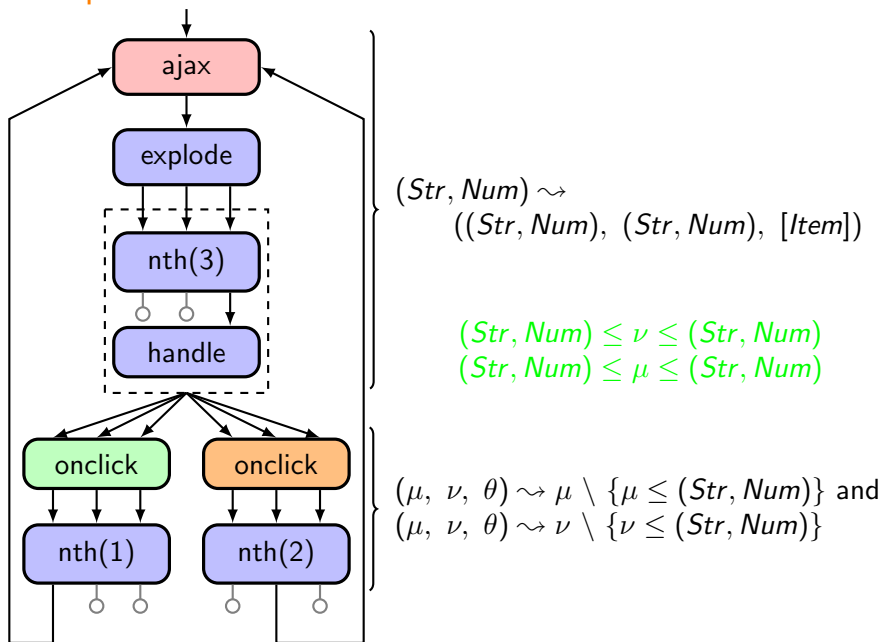
Composition-Time Inference



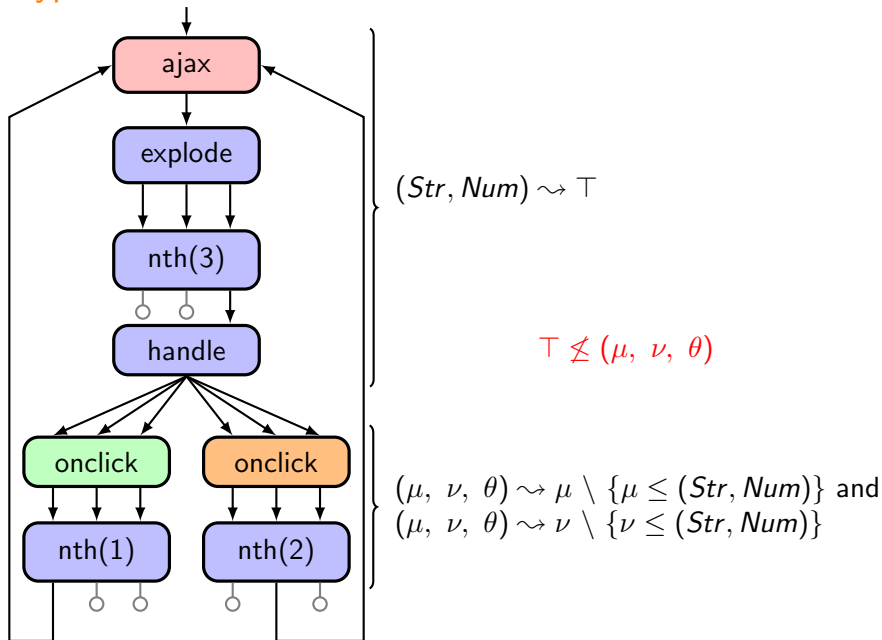
Composition-Time Inference



Composition-Time Inference

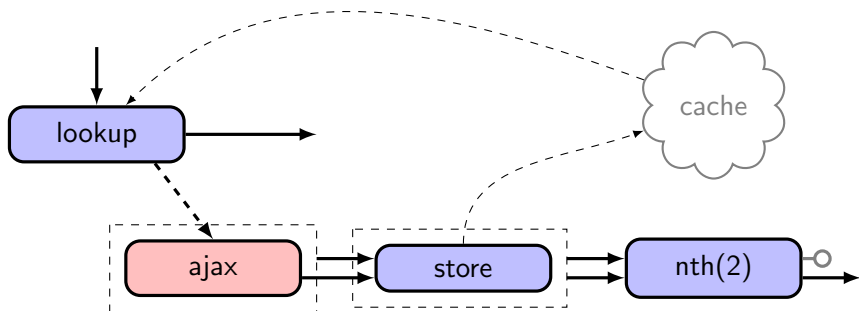


Type Clash Detection



Adding Optimizations

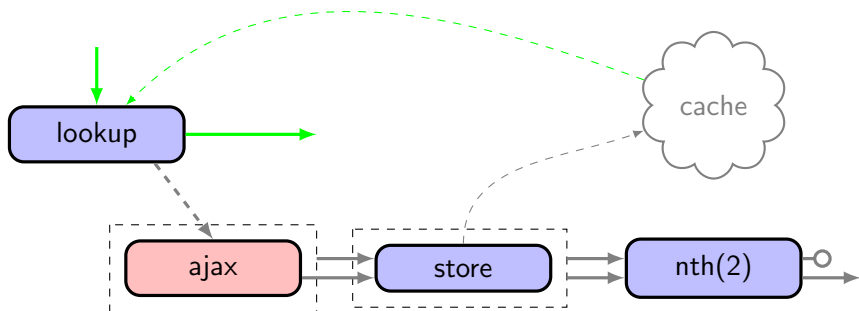
Cached Ajax Responses



```
const cachedAjax = Arrow.catch(lookup, Arrow.seq([
  ajax.carry(),
  store.remember(),
  new NthArrow(2)
]));
```

```
function lookup(key) {
  if (key in cache) return cache[key];
  else               throw key;
}
```

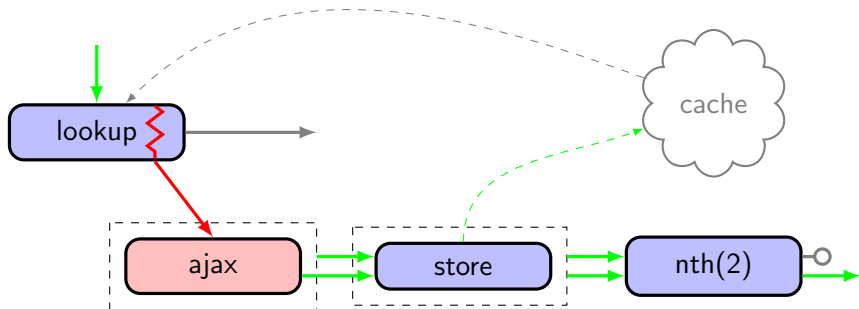
Cached Ajax Responses



```
const cachedAjax = Arrow.catch(lookup, Arrow.seq([
  ajax.carry(),
  store.remember(),
  new NthArrow(2)
]));
```

```
function lookup(key) {
  if (key in cache) return cache[key];
  else              throw key;
}
```

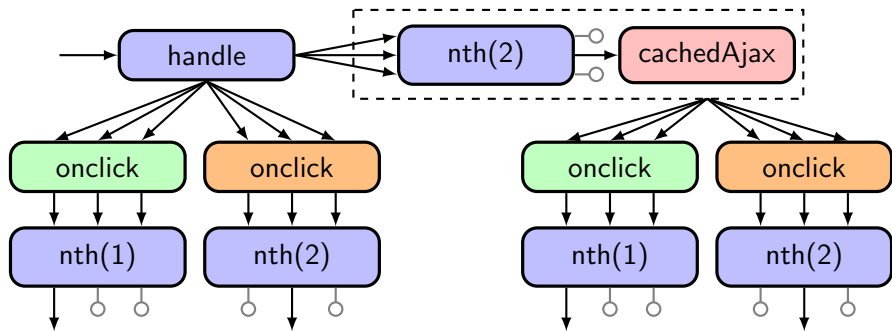
Cached Ajax Responses



```
const cachedAjax = Arrow.catch(lookup, Arrow.seq([
  ajax.carry(),
  store.remember(),
  new NthArrow(2)
]));
```

```
function lookup(key) {
  if (key in cache) return cache[key];
  else              throw key;
}
```

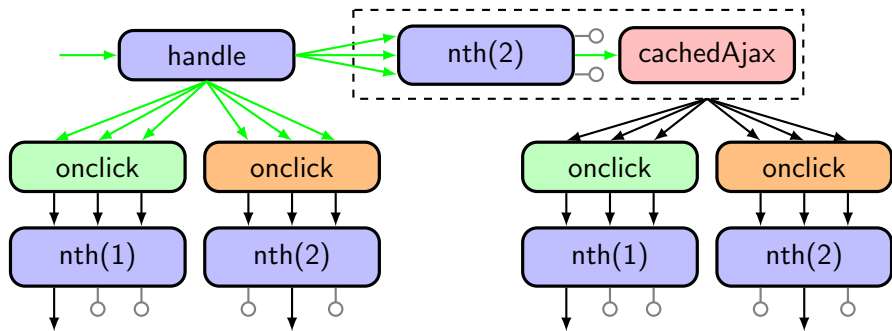
Pre-Fetching Next Page



```
const progress = Arrows.any([
  new NthArrow(1).onclick('#prev'),
  new NthArrow(1).onclick('#next')
]);

Arrow.any([progress, Arrow.seq([
  Arrow.seq([new NthArrow(2), cachedAjax]).remember(),
  progress
])]);
```

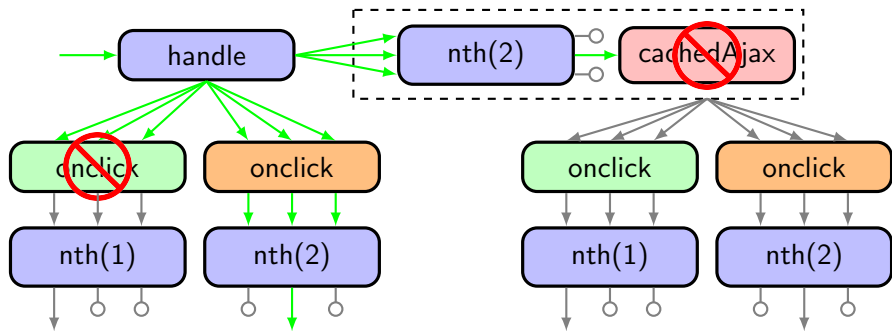
Pre-Fetching Next Page



```
const progress = Arrows.any([
  new NthArrow(1).onclick('#prev'),
  new NthArrow(1).onclick('#next')
]);

Arrow.any([progress, Arrow.seq([
  Arrow.seq([new NthArrow(2), cachedAjax]).remember(),
  progress
])]);
```

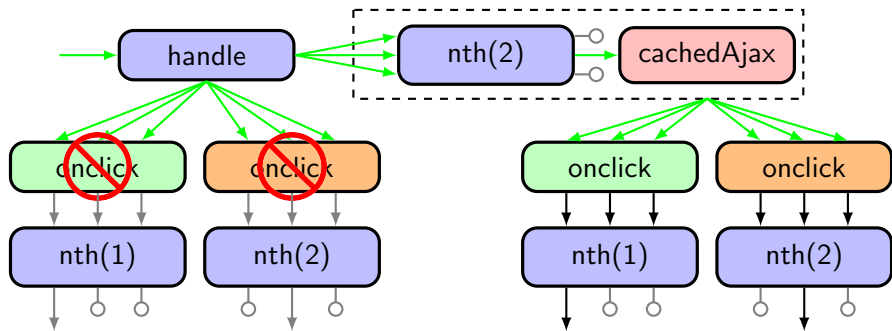
Pre-Fetching Next Page



```
const progress = Arrows.any([
  new NthArrow(1).onclick('#prev'),
  new NthArrow(1).onclick('#next')
]);

Arrow.any([progress, Arrow.seq([
  Arrow.seq([new NthArrow(2), cachedAjax]).remember(),
  progress
])]);
```

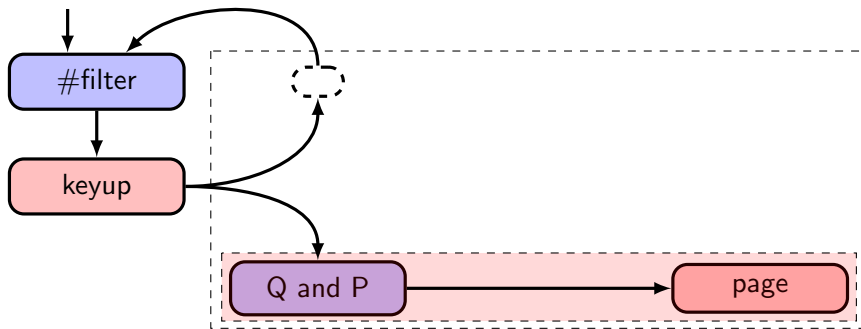
Pre-Fetching Next Page



```
const progress = Arrows.any([
  new NthArrow(1).onclick('#prev'),
  new NthArrow(1).onclick('#next')
]);

Arrow.any([progress, Arrow.seq([
  Arrow.seq([new NthArrow(2), cachedAjax]).remember(),
  progress
])]);
```

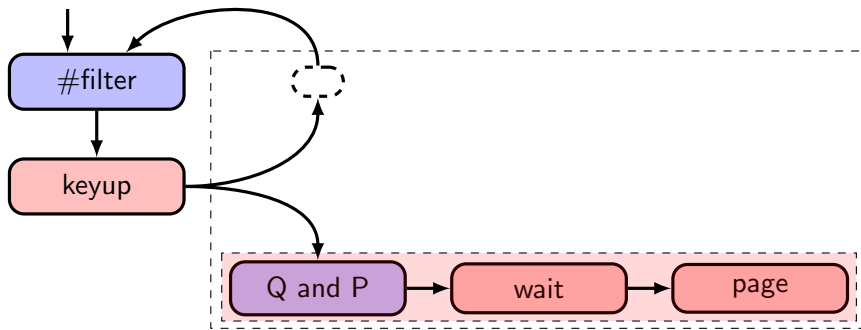

No In-Flight Requests as User Types



```
let filter = Arrow.fix(a => Arrow.any([
  a,
  Arrow.seq([
    getQueryAndPage,

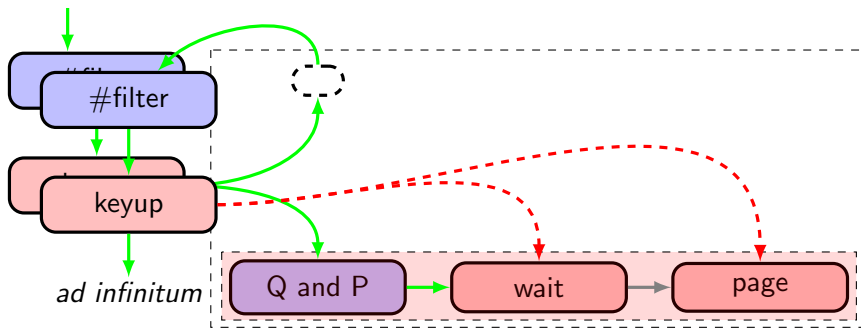
    page
  ]).noemit(),
]).onkeyup('#filter'));
```

No In-Flight Requests as User Types



```
let filter = Arrow.fix(a => Arrow.any([
  a,
  Arrow.seq([
    getQueryAndPage,
    new DelayArrow(400),
    page
  ]).noemit(),
]).onkeyup('#filter'));
```

No In-Flight Requests as User Types



```
let filter = Arrow.fix(a => Arrow.any([
  a,
  Arrow.seq([
    getQueryAndPage,
    new DelayArrow(400),
    page
  ]).noemit(),
]).onkeyup('#filter'));
```

Conclusion

Composing an *interaction machine* is a powerful shift in abstraction
Opens up opportunity for 'static' benefits

Conclusion

Composing an *interaction machine* is a powerful shift in abstraction
Opens up opportunity for 'static' benefits

Examples, papers, and code available at
<http://arrows.eric-fritz.com>

Conclusion

Composing an *interaction machine* is a powerful shift in abstraction
Opens up opportunity for 'static' benefits

Examples, papers, and code available at
<http://arrows.eric-fritz.com>

Questions?