Ohua: Implicit Dataflow Programming for Concurrent Systems

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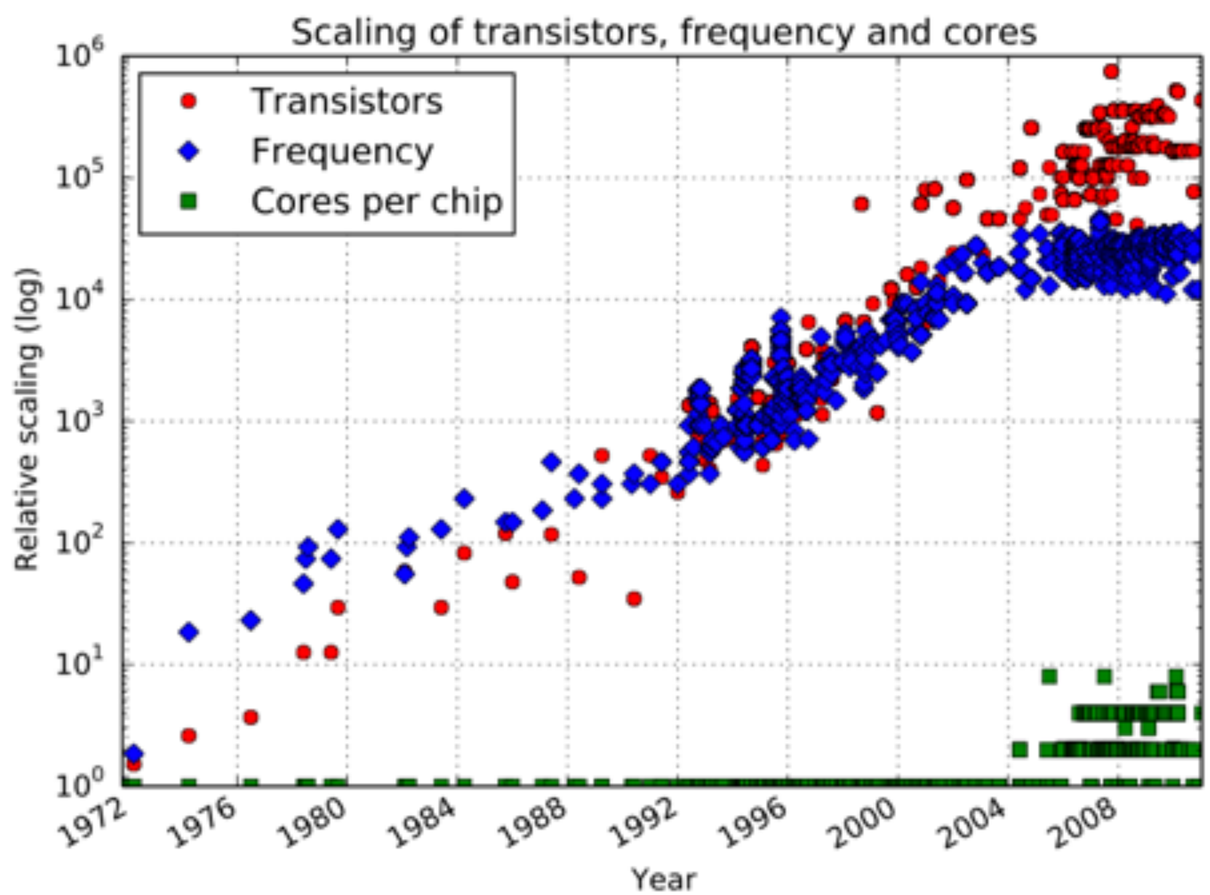
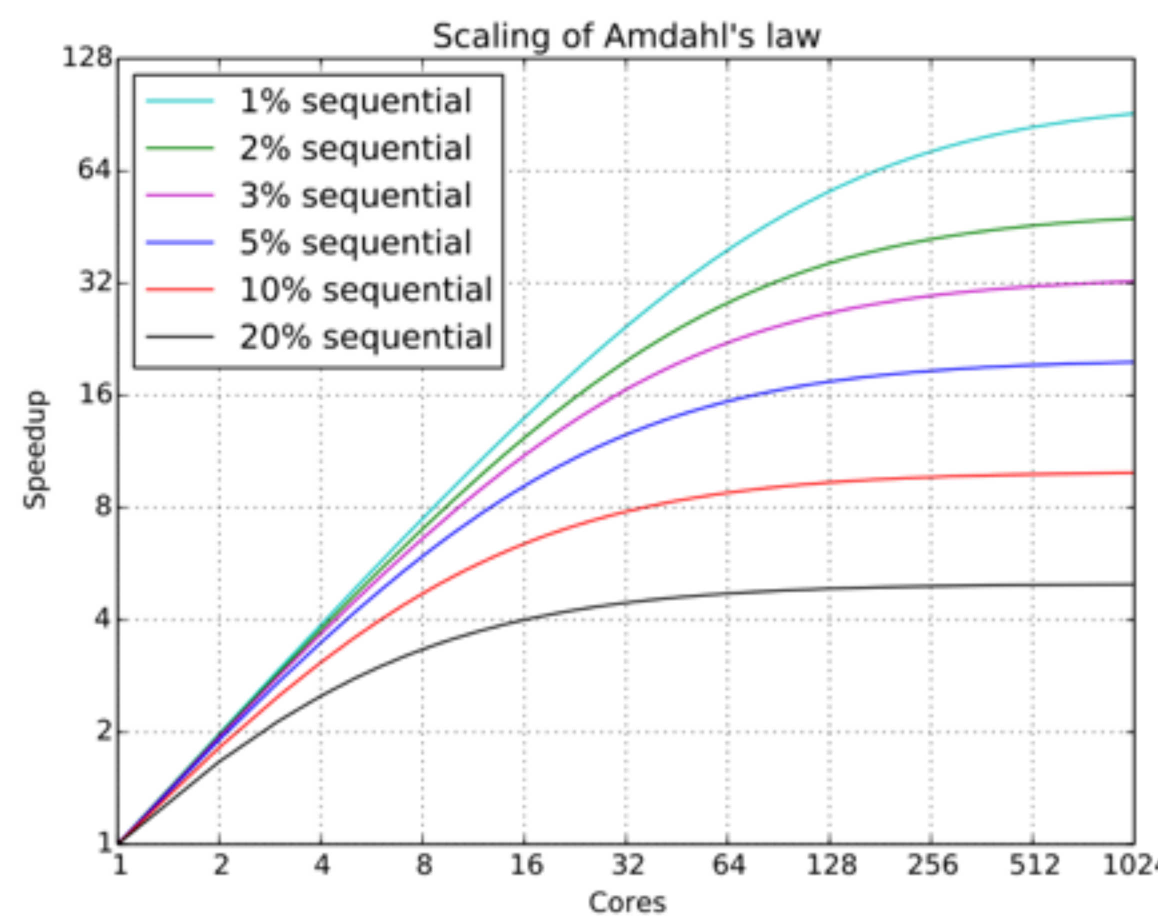
The Multi-Core Future





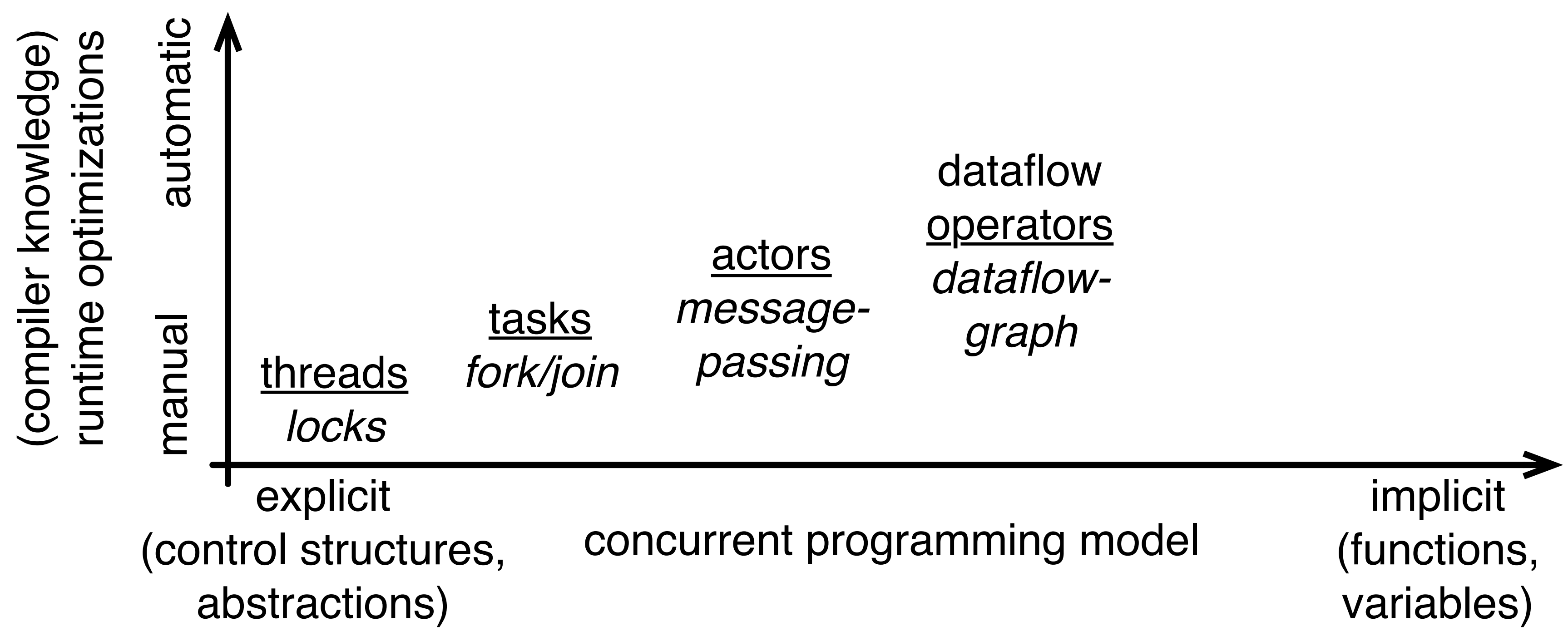
Jons-Tobias Wamhoff. 2014. Exploiting Speculative and Asymmetric Execution on Multicore Architectures (Dissertation)

Parallelism

- Lesson learned (for general purpose programming):
  - Work granularity must compensate scheduling overheads:
    - ➪ Coarse-grained parallelism
    - ➪ Concurrent programming

Tim Harris and Satnam Singh. Feedback directed implicit parallelism. ICFP '07

Concurrent Programming



- All models depart from sequential programming style.
  - ➪ Scalability in programming effort suffers.
  - ➪ Limited compiler support for optimizations.

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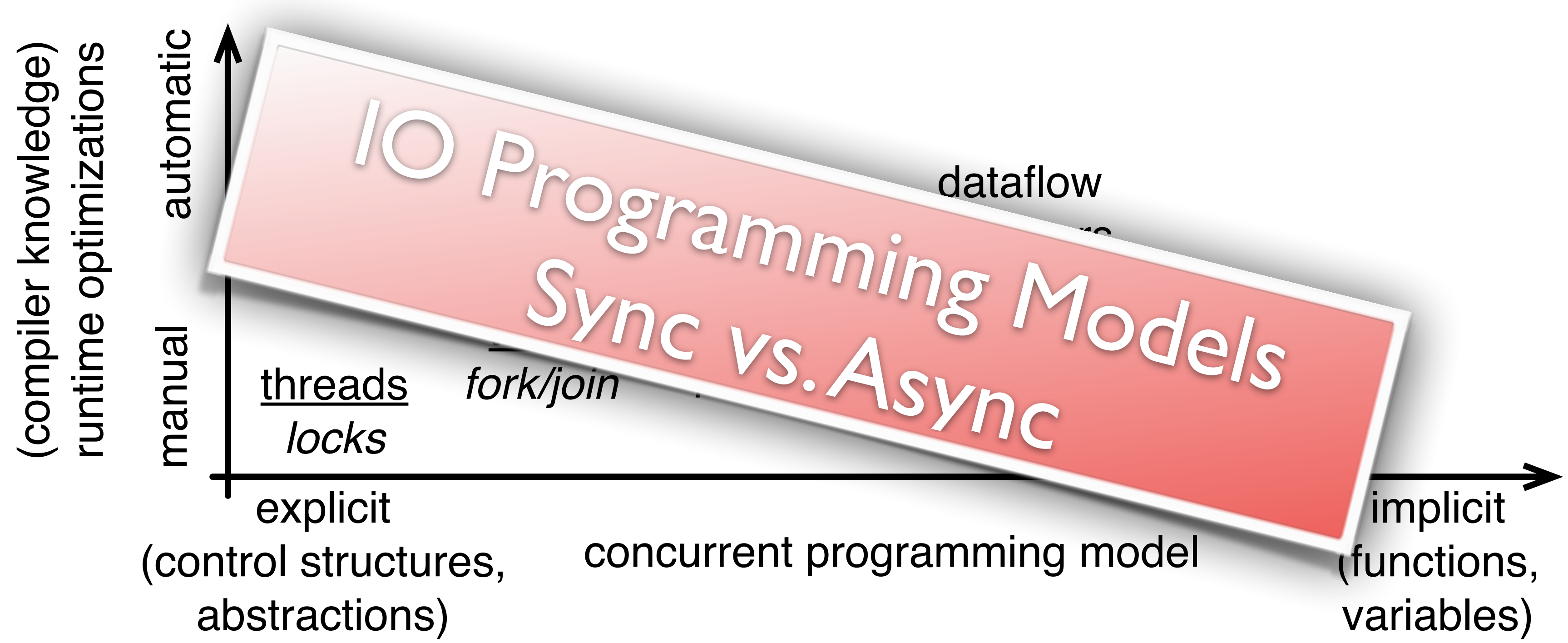

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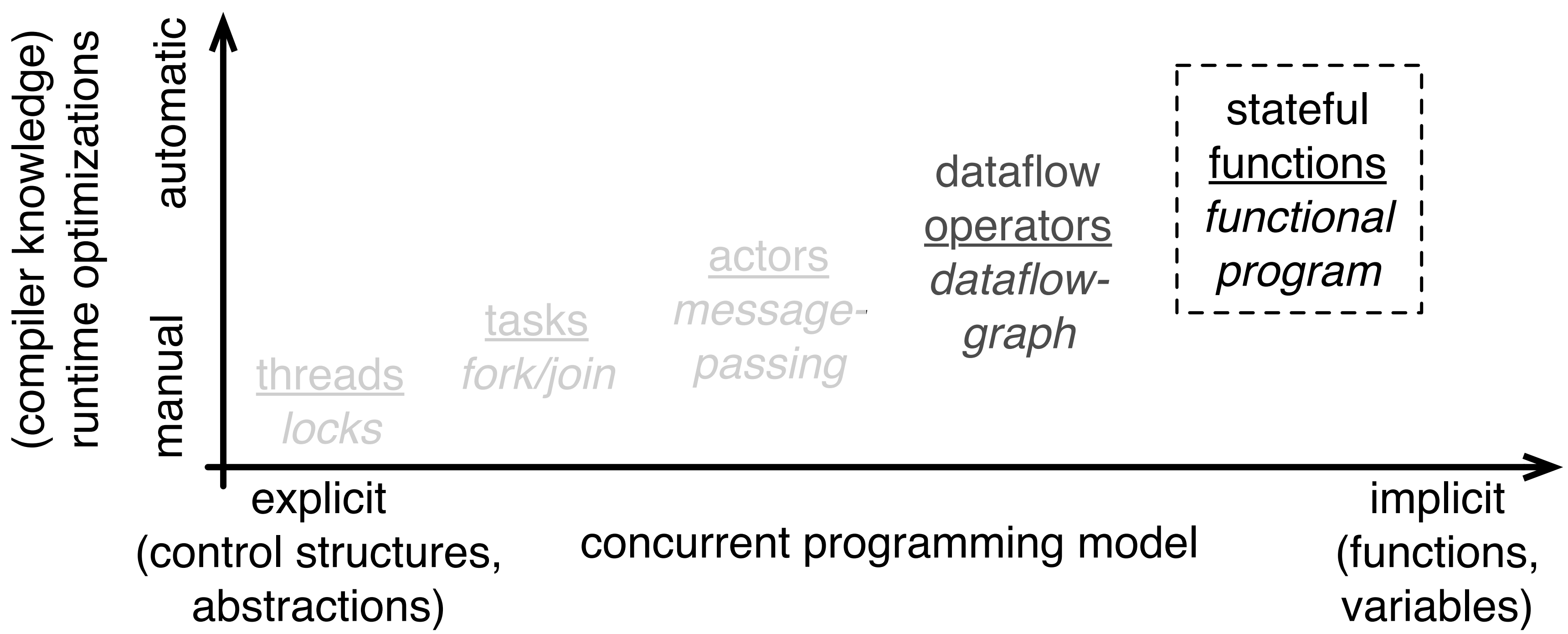


- Key observation:
  - ➪ Algorithms are composed out of functionality.

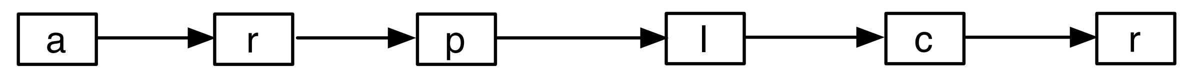
From dataflow programming to stateful functional programming (SFP)

- Example: simple web server

```
public class WebServer extends StreamFlexGraph {
  private Filter a, r, p, l, c, rep;

  public WebServer() {
    // explicit dataflow graph construction
    a = makeFilter(Accept.class);
    r = makeFilter(Read.class);
    p = makeFilter(Parse.class);
    l = makeFilter(Load.class);
    c = makeFilter(Compose.class);
    rep = makeFilter(Reply.class);
    connect(a, r);
    connect(r, p);
    connect(p, l);
    connect(l, c);
    connect(c, rep);
    validate();
  }

  public void start() {
    new Synthetizer(a).start();
    super.start();
  }
}
```



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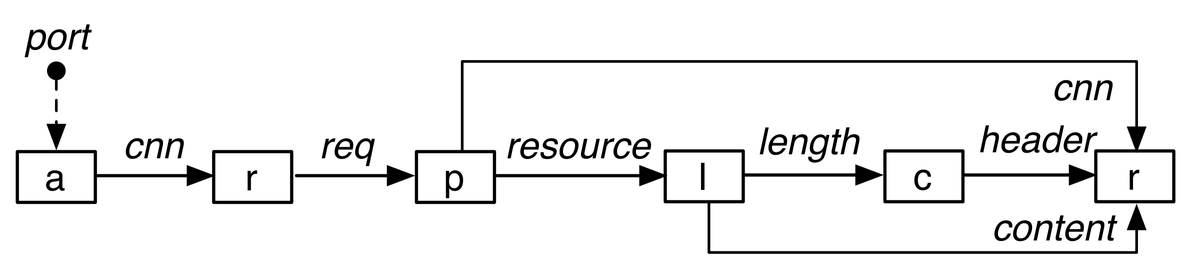
```clojure
(defn start [port]
  (ohua
    ; most "explicit"/fine-grained data dependency matching
    (let [[cnn req] (read (accept port))]
      (let [[_ resource _] (parse req)]
        (let [[content length] (load resource)]
          (reply cnn (compose length) content))))))
```



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From dataflow programming to stateful functional programming (SFP)

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class FileLoad extends Filter {
  Channel<String> in, out;
  Map<String, String> cache = new HashMap<>();

  void work() {
    // explicit channel control
    String resource = in.take();
    String contents = null;
    // load file data from disk or cache (omitted)
    out.put(contents);
  }
}
```

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class FileLoad {
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  @Function
  String load(String resource) {
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```

- Functions instead of channels!
- Stateful functions ➪ state encapsulation
  - Implemented in imperative language/style.

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```

```clojure
(ns com.server.FileLoad
  (:gen-class :state cache :init init
    :methods [[^{Function} load [String] String]]))

(defn -init [] [[] {}]) ; create a hash map
(defn -load [this resource]
  (if (contains? (.cache this) resource)
    (get (.cache this) resource)
    (let [content (slurp resource)]
      (set! (.cache this) (assoc (.cache this) resource content))
      content)))
```

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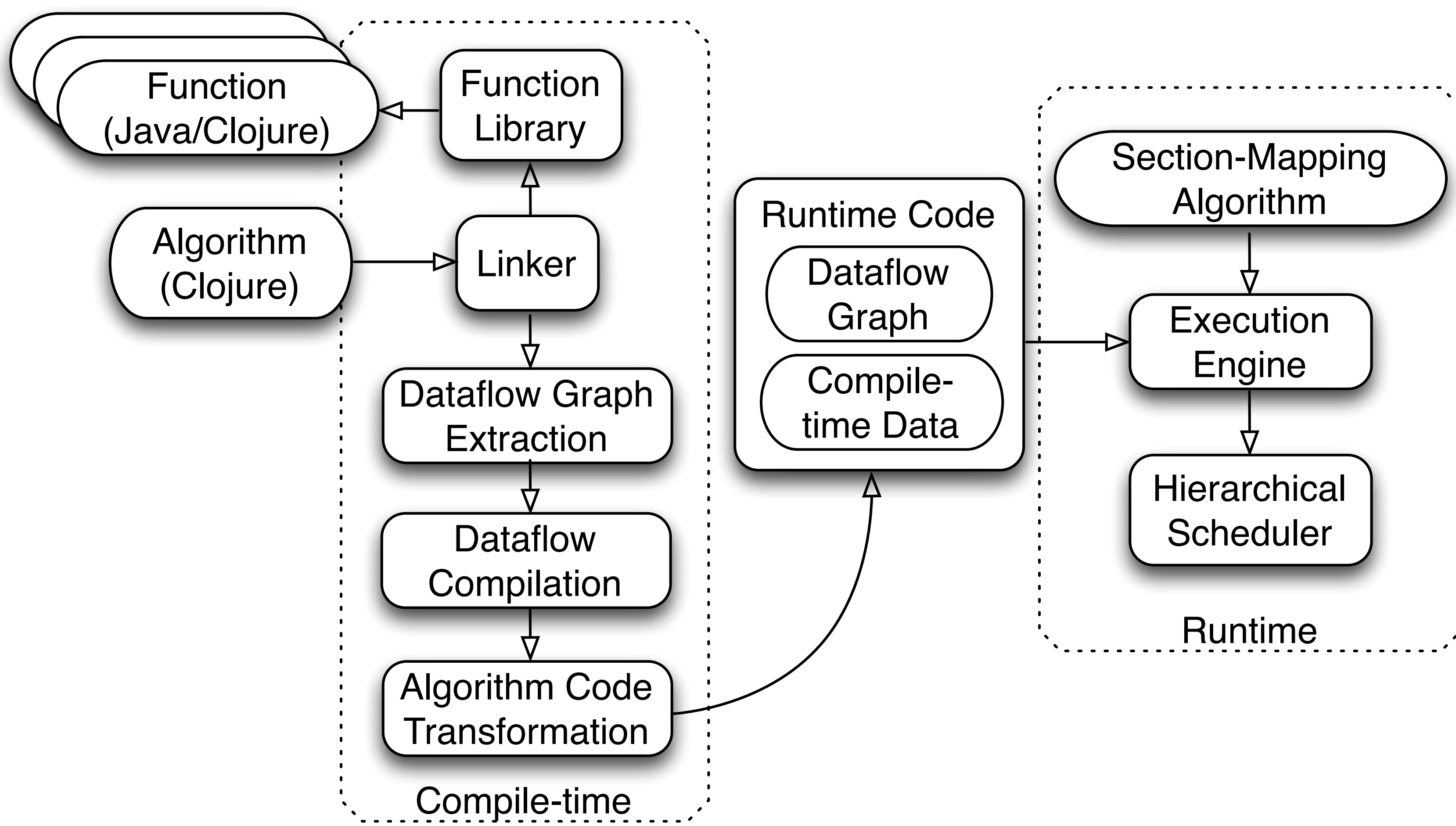
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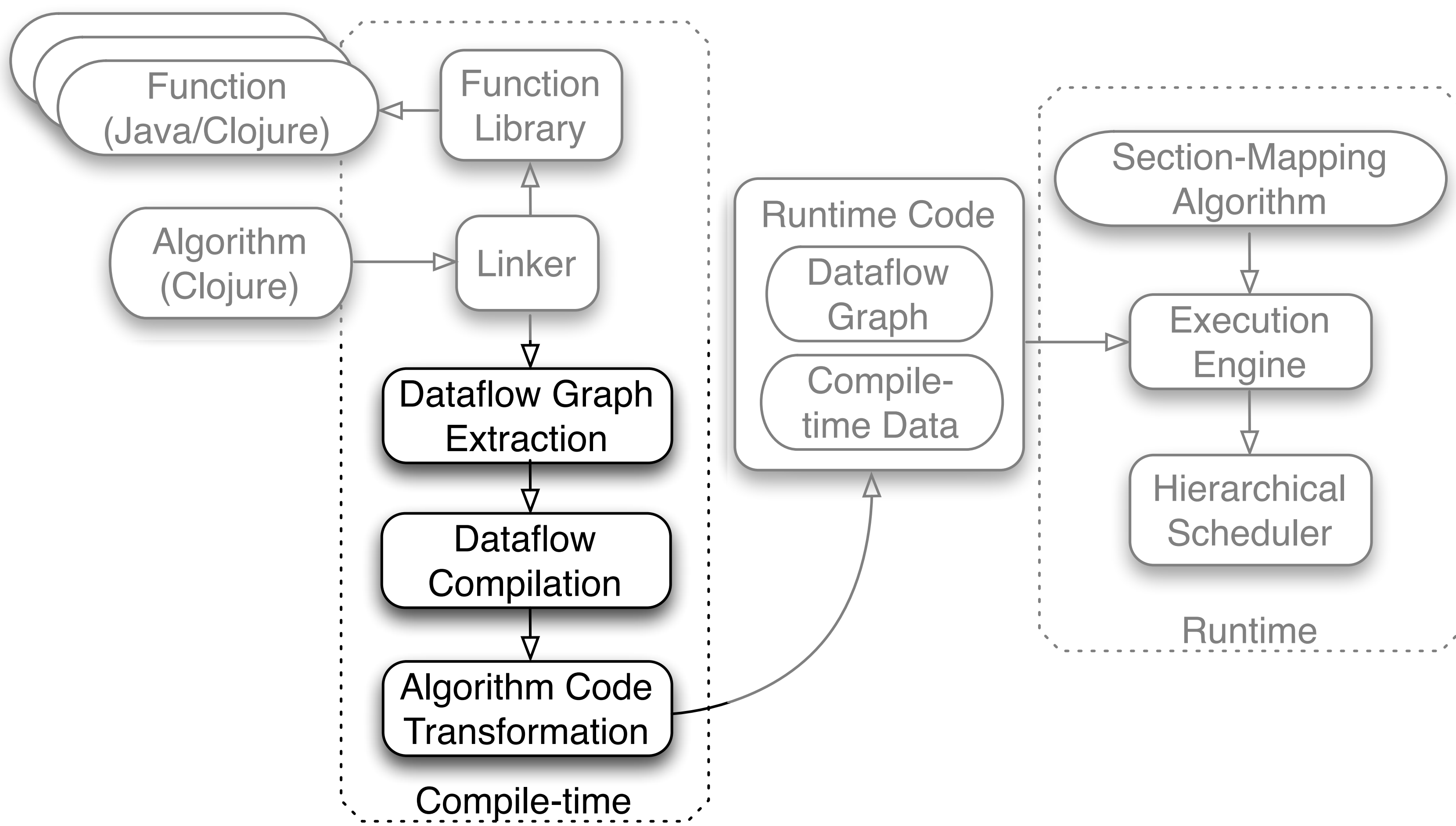
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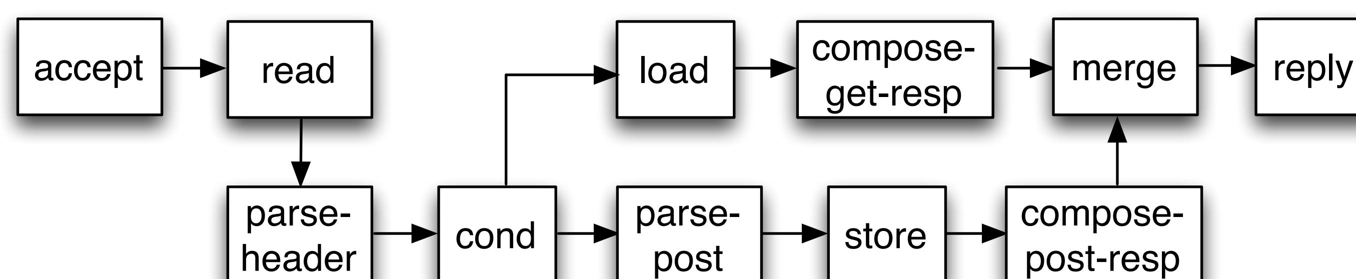
From Control Flow to Dataflow

- Construction of a control flow dependence graph.

```
(ohua
  (let [[type req] (-> 80 accept read parse-header)]
   (if (= type "GET")
    (-> req load compose-get-resp)
    (-> req parse-post store compose-post-resp))
   reply))
```



- Most special forms of Clojure supported.

Micah Beck, Richard Johnson, and Keshav Pingali. 1991. From control flow to dataflow. J. Parallel Distrib. Comput.

Closures and Destructuring

- Closures in combination with destructuring create opportunities for enhanced parallelism.
- || macro construction for parallel request handling:

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```
(ohua
 (let [cnn (accept 80)]
   (let [[one two three] (balance-data cnn)]
     (-> one read parse load compose reply)
     (-> two read parse load compose reply)
     (-> three read parse load compose reply))))
```

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```
 one two three
[cnn nil nil]
[nil cnn nil]
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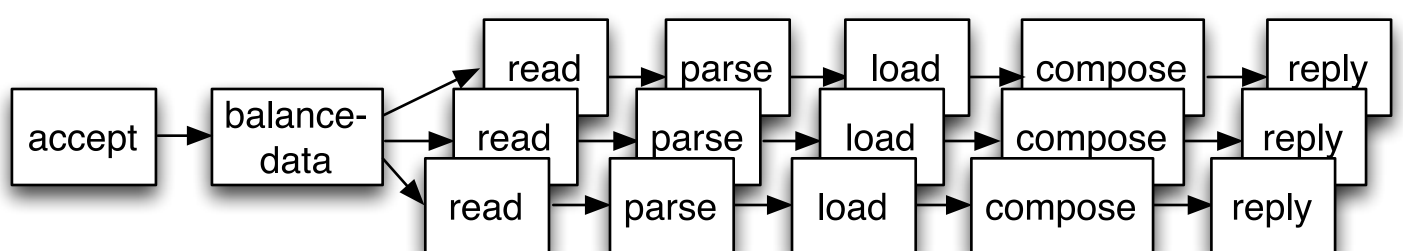

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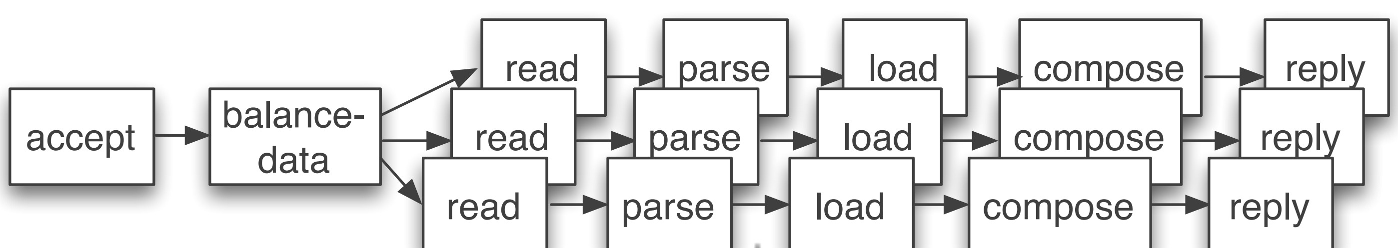

Beware:
Each operator/function *invocation* has its own state!

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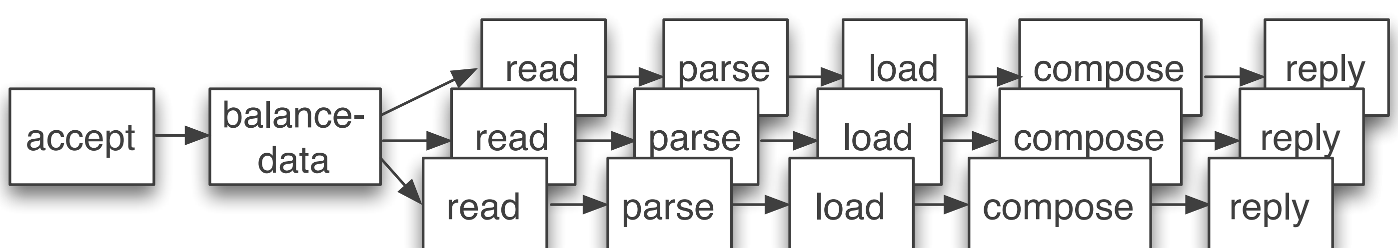


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  (let [cnn (accept 80)]
    (|| 3 cnn (-> read parse load compose reply))))
```
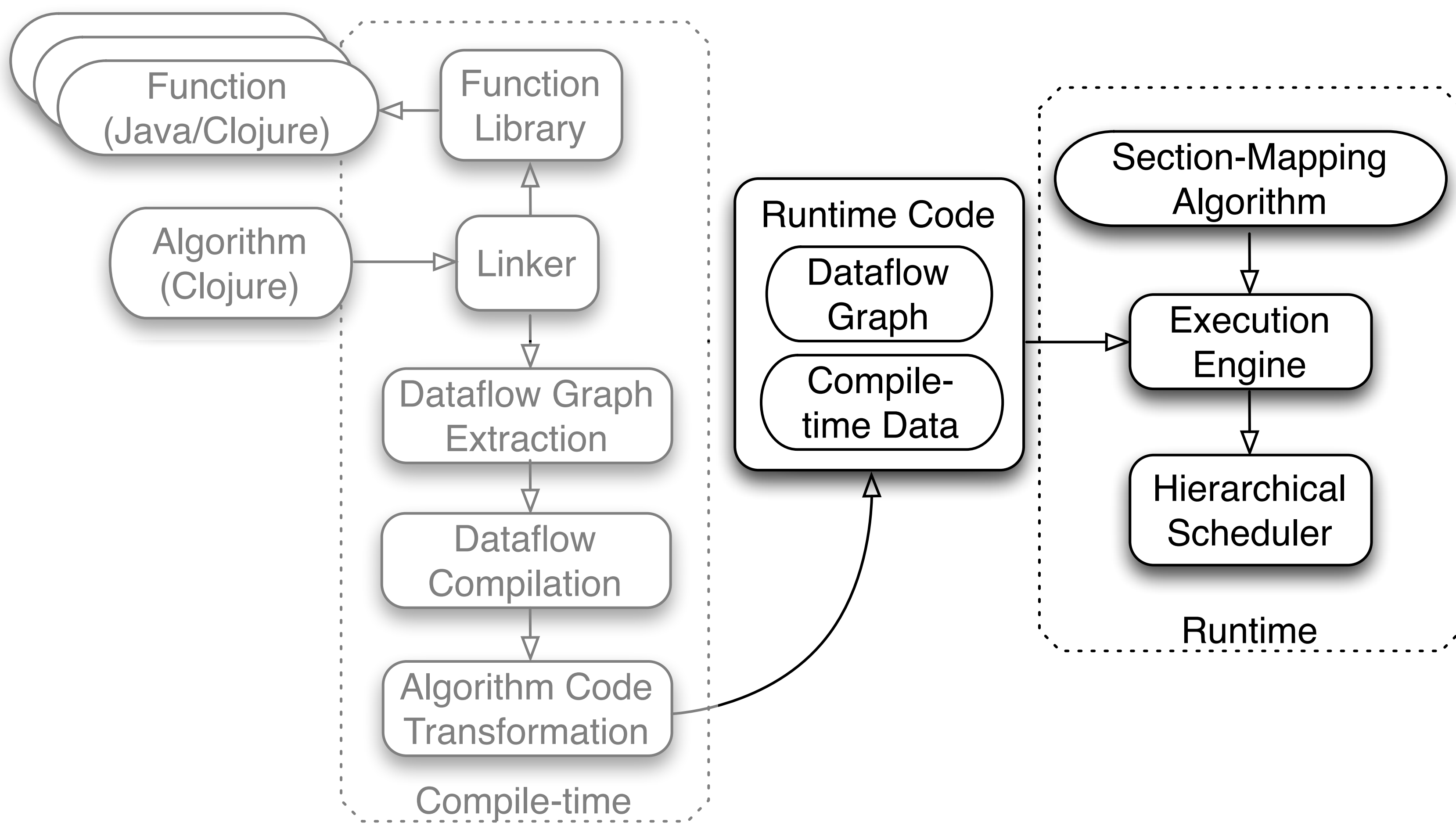

Ohua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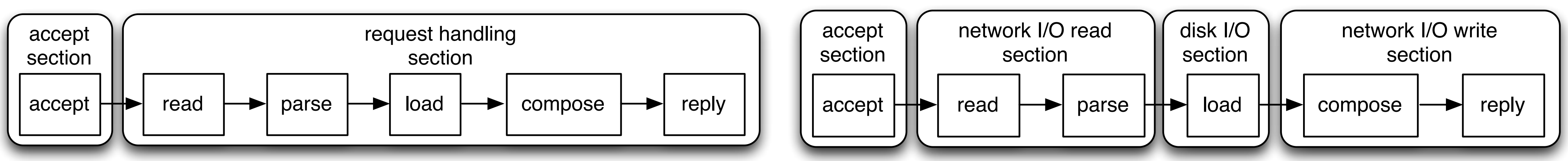
Sections

- Dataflow execution model: pipeline parallelism.
- Section: set of one or more operators.

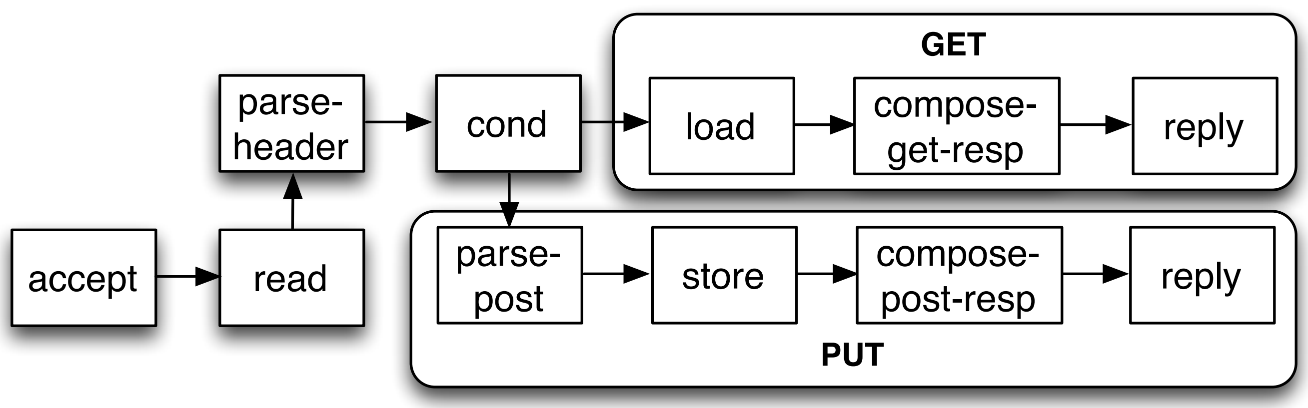


- Construct section mapping from execution restrictions.

- Hierarchical scheduling:
  - Sections executed across thread pool ➪ parallel.
  - Operators scheduled cooperatively ➪ sequential.

Synchronization

- Sections provide lock-free synchronization!
- Consider parallel request handling by type:



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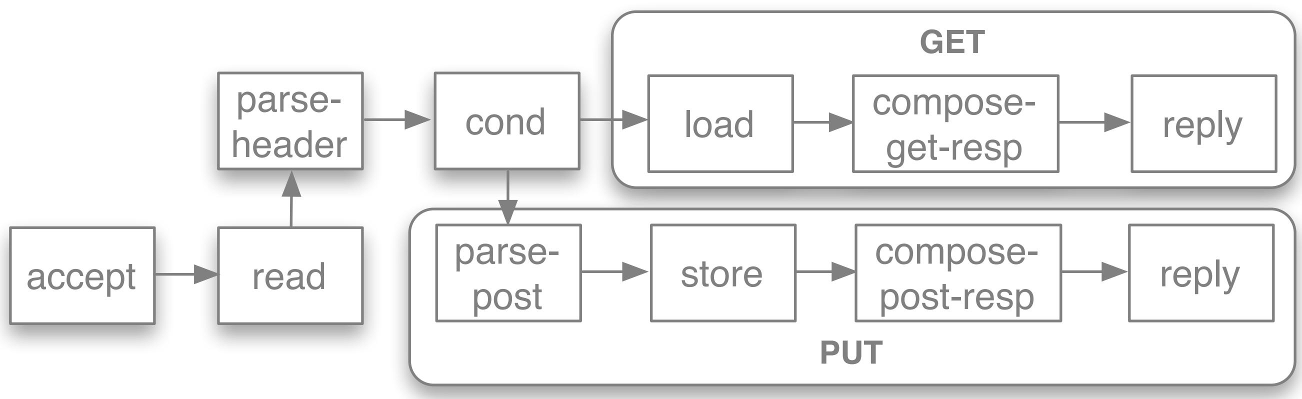

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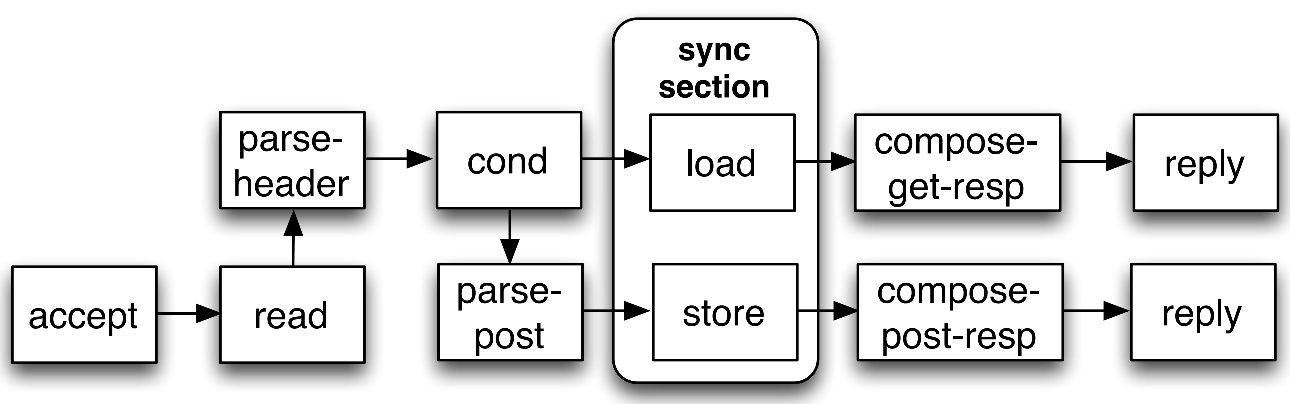
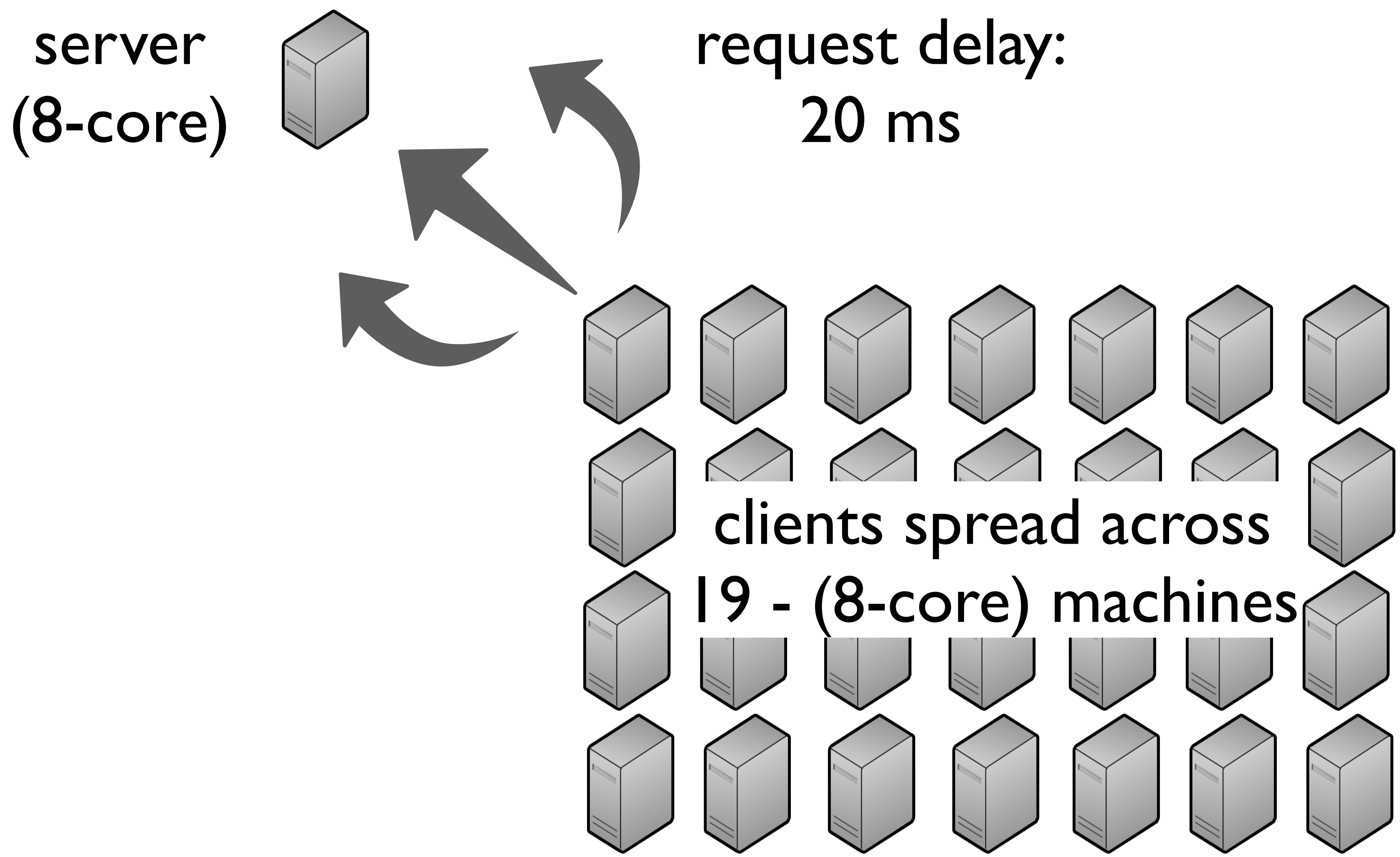


Experimental Setup



Section Strategies

- Goal: web server fine-tuning without code changes.

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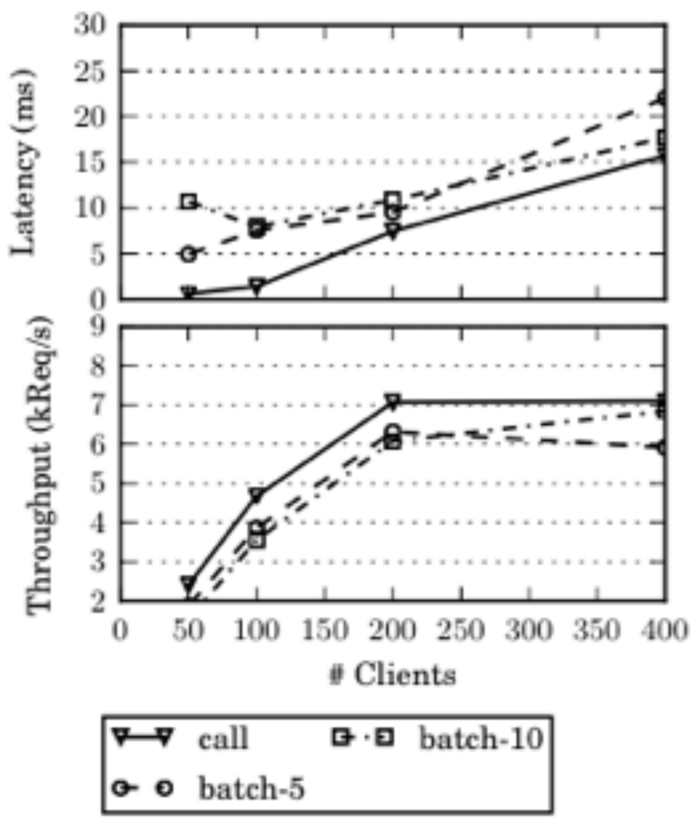

(a) Operator Scheduling Overhead

- Best deployment strategy: call

Section Strategies

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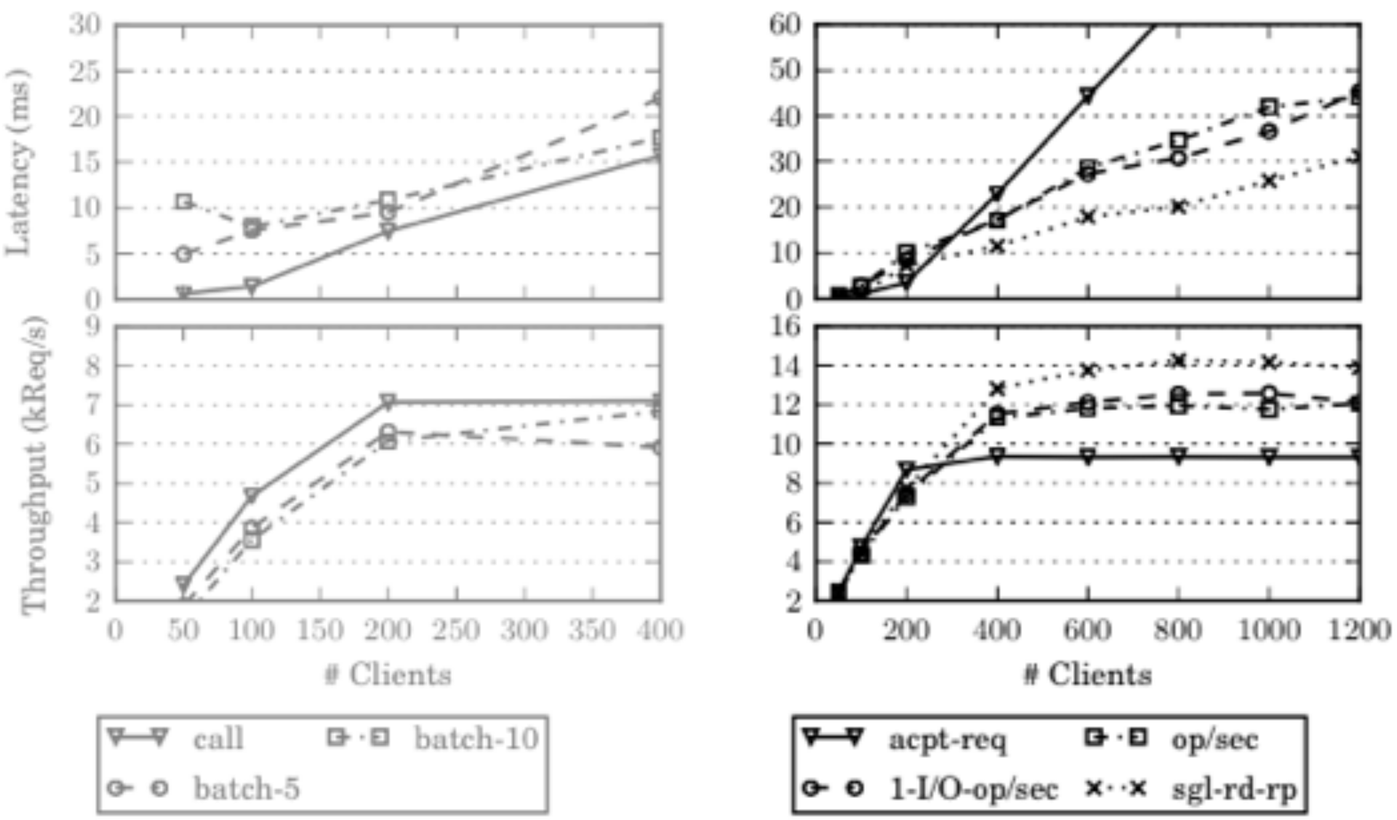
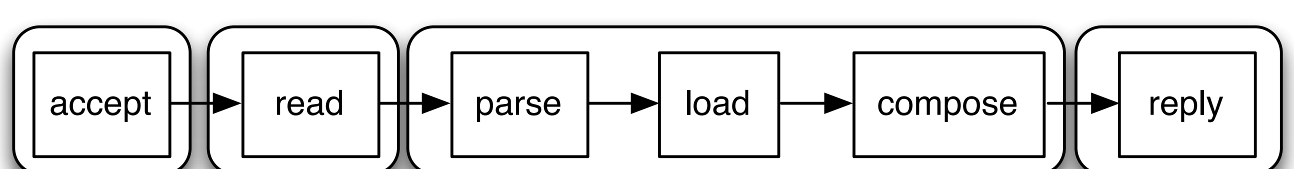


(a) Operator Scheduling Overhead (b) Section Mapping Comparison

- Best deployment strategy: call/sgl-rd-rp



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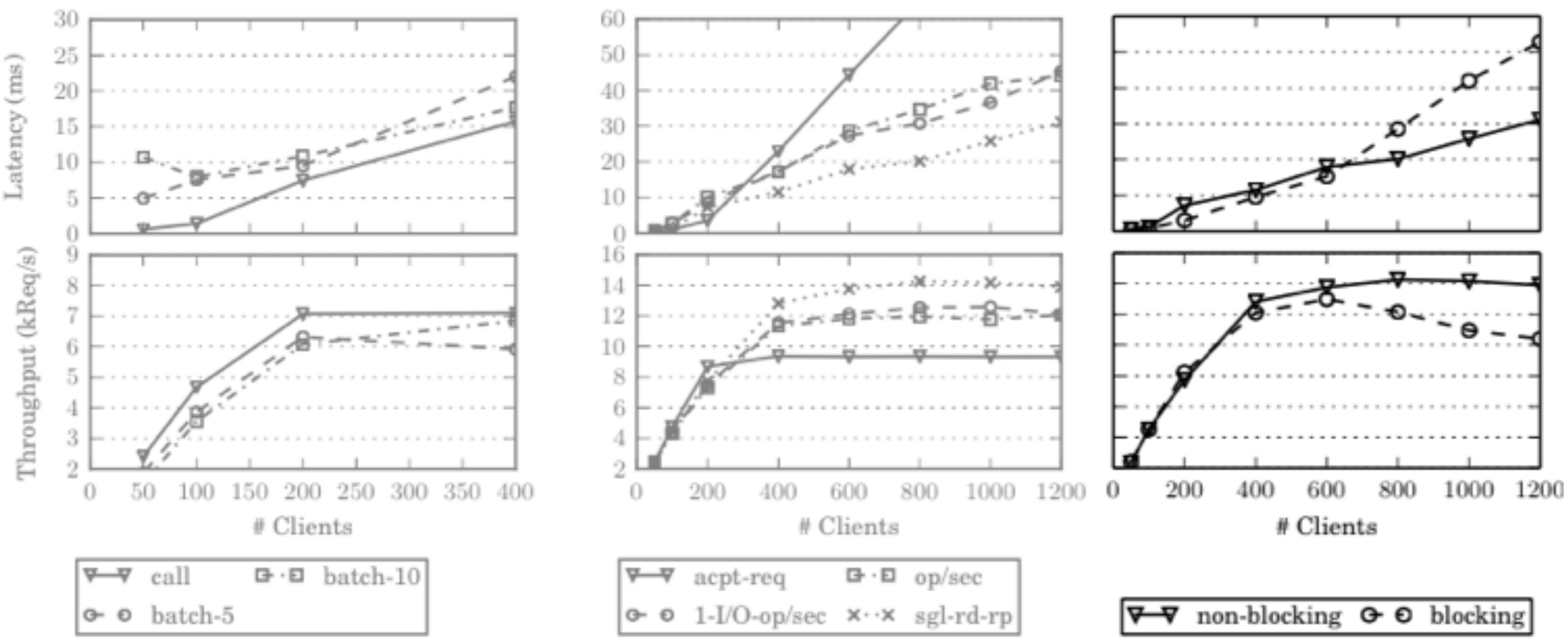
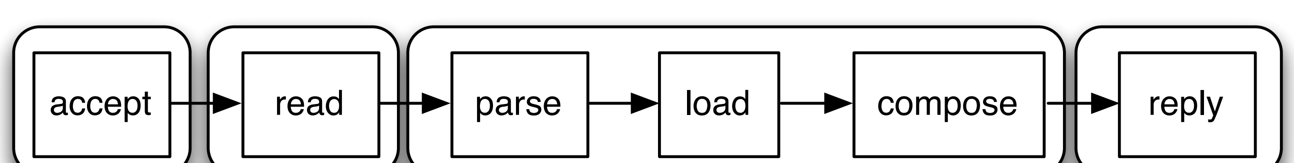


(a) Operator Scheduling Overhead (b) Section Mapping Comparison (c) Section Scheduling Overhead

- Best deployment strategy: call/sgl-rd-rp/non-blocking



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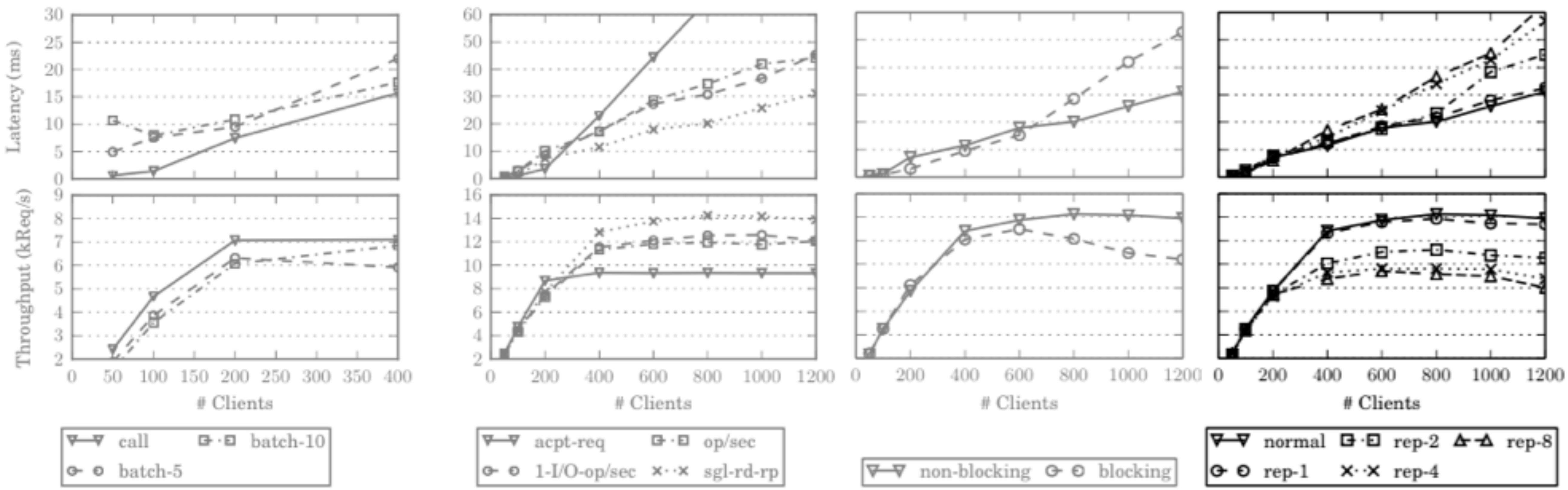
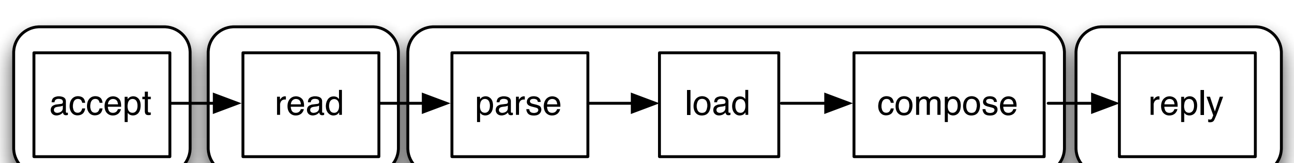
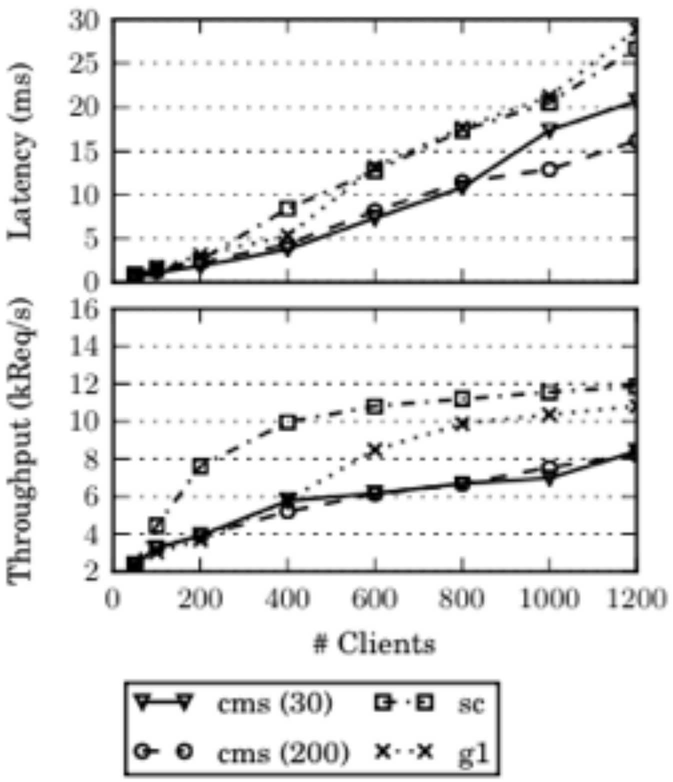


(a) Operator Scheduling Overhead (b) Section Mapping Comparison (c) Section Scheduling Overhead **(d) Data Parallelism Impact**

- Best deployment strategy: call/sgl-rd-rp/non-blocking/normal

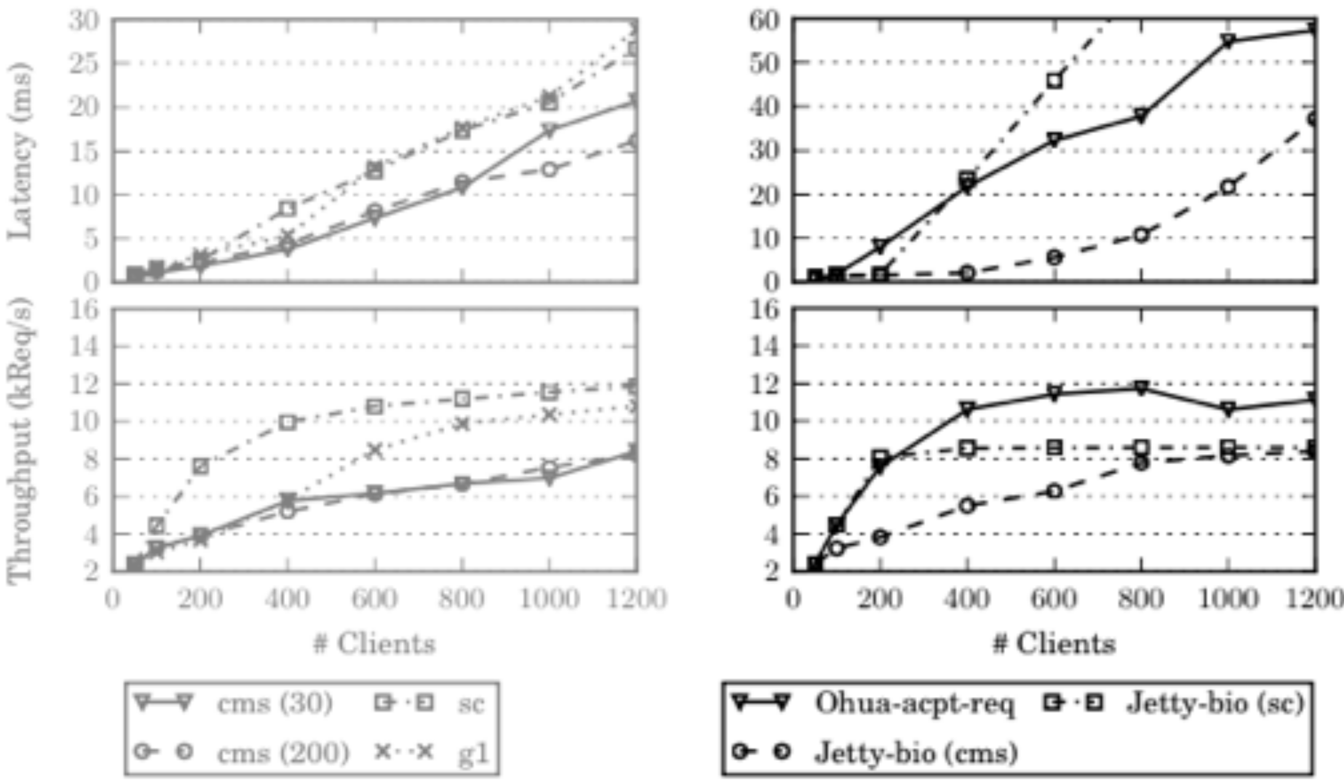


Jetty vs. Ohua



(a) Jetty GC

Jetty vs. Ohua



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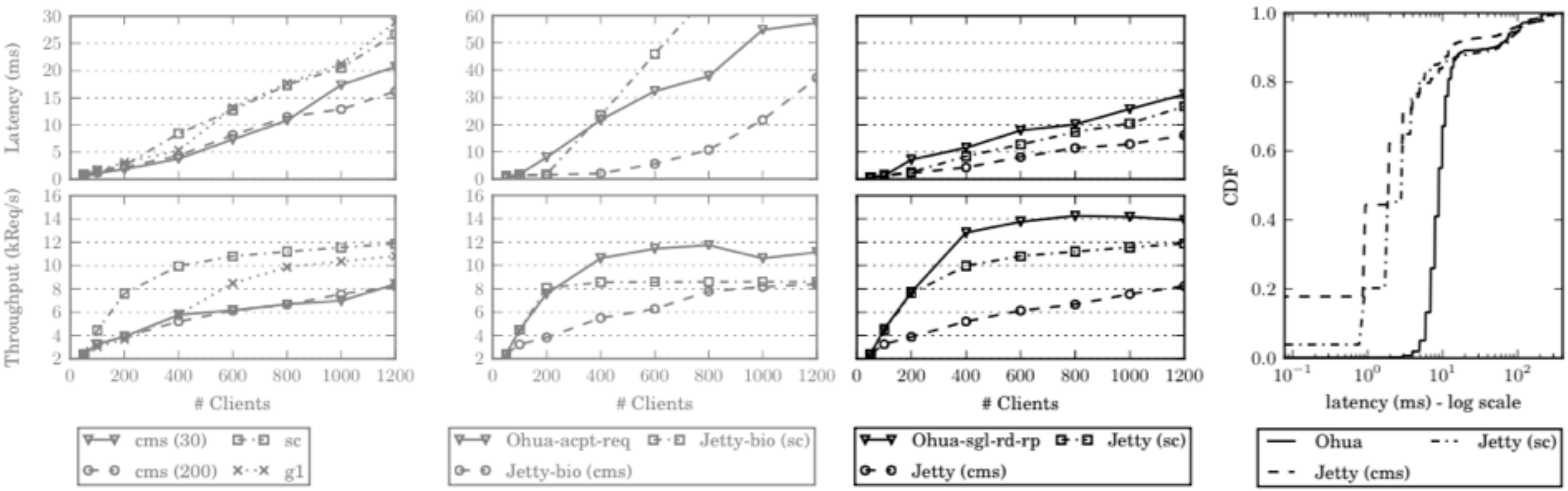


(a) Jetty GC (b) BIO (c) Async NIO (d) Req. latency

- Ohua is ➪ comparable to Jetty (NIO) in terms of latency,
  ➪ outperforms Jetty (NIO) in terms of throughput,
  ➪ but without pre-selecting the GC and
  ➪ without mixing programming models.

Stateful Functional Programming (SFP)

- SFP programming model:

  program = *declarative* algorithms + *stateful* functions

- Benefits:
  - ➪ Scalable system construction via algorithm composition.
  - ➪ Implicit parallelism for algorithms.

- Future work: (tip of the ice berg)
  - ➪ No deadlocks or data races.
  - ➪ Leverage dataflow experience for runtime optimizations.

Thanks for your attention!

Questions?

https://clojars.org/ohua

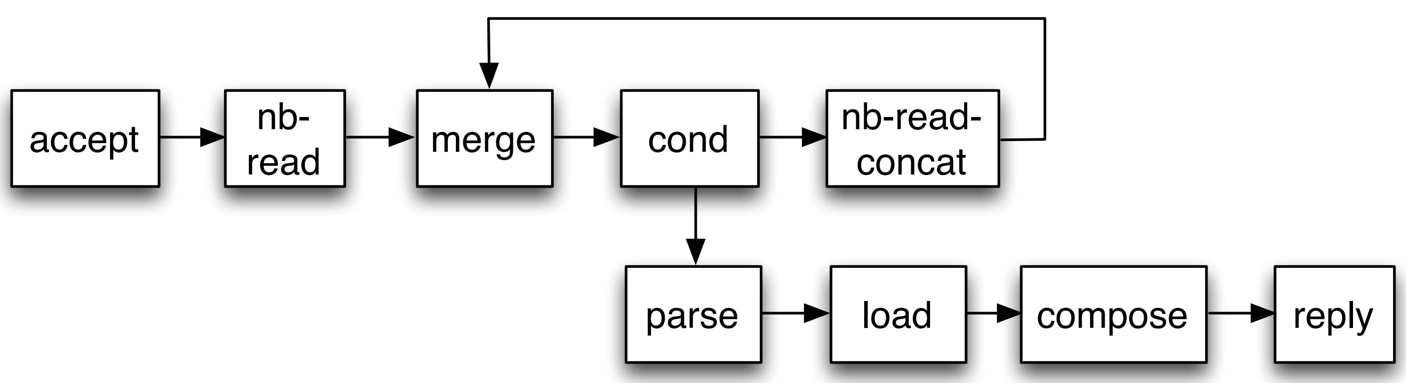
https://bitbucket.org/sertel/ohua

https://bitbucket.org/sertel/ohua-server

Loops

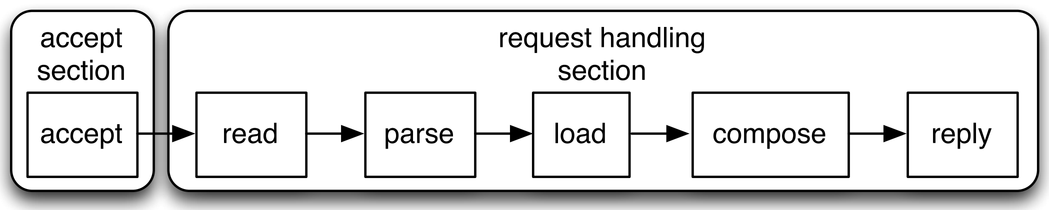
- Example: non-blocking read

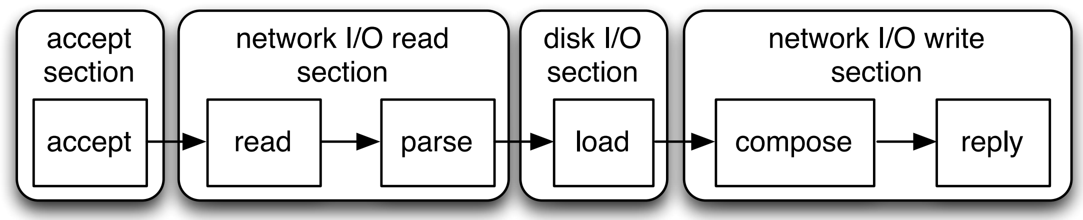
```
(ohua
  (reply (compose (load (parse
                        (loop [[read-data cnn] (nb-read (accept 80))]
                          (if (.endsWith read-data "\n\n") ; stop on blank line
                            [read-data cnn]
                            (recur (nb-read-concat cnn read-data)))))))))
```



- Beware of state inside loops!

Sections



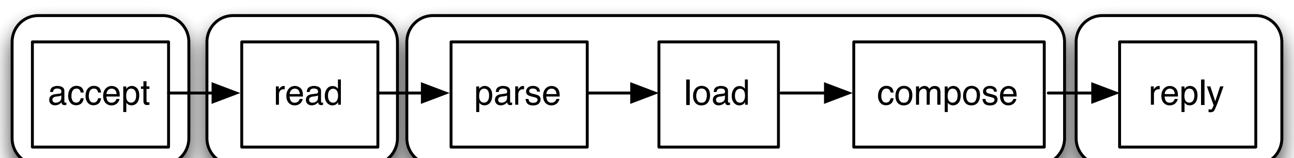


- Manual section configuration via regular expressions:

```
'(["accept.*"] ["read.*" "parse.*" "load.*" "compose.*" "reply.*"])
```

```
'(["accept.*"] ["read.*" "parse.*"] ["load.*"] ["compose*" "reply.*"])
```

- Restrictions:




```
(doto (new java.util.Properties)
  (.put "section-strategy" "com.ohua.LooseConfigurableSectionMapping")
  (.put "section-config" '(["parse.*" "load.*" "compose.*"])))
```

- Ultimate goal: automatic section configuration.

Type sensitive request handling

```
(ohua
  (let [[_ resource-ref] (-> 80 accept read parse)]
    (if (.startsWith resource-ref "news/")
      (-> resource-ref load-ram write reply)
      (-> resource-ref load-hd write reply))))
```

- Scenario: small feeds in RAM vs. articles on disk
- Goal: unblock feeds from articles

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