Parallel & Concurrent Programming:

Server Architectures and Beyond

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Outline

- Last time:
  - Server **architectures**
    - Focus: web servers
    - Performance & ease of programming
  - Result – event-driven + helpers seems "better"
- Today:
  - Can we have our cake and eat it, too?
    - Where "cake" = performance + ease of programming

Server Architectures

Recap:

- **MT/MP**
  - Context switch overhead
  - Race conditions, etc.
- **SPED**
  - High throughput, but complex
  - Blocking I/O
- **AMPED**
  - Better than SPED, but still hard to program

Are Threads Just Broken?

- Events too hard:
  Can we fix threads instead?
- More natural abstraction, but:
  - **Scalability limit**
    - Stack size problem:
      2 MB per stack = 1000 thread limit
  - **No admissions control** (à la SEDA)
- Still stuck with potential races…

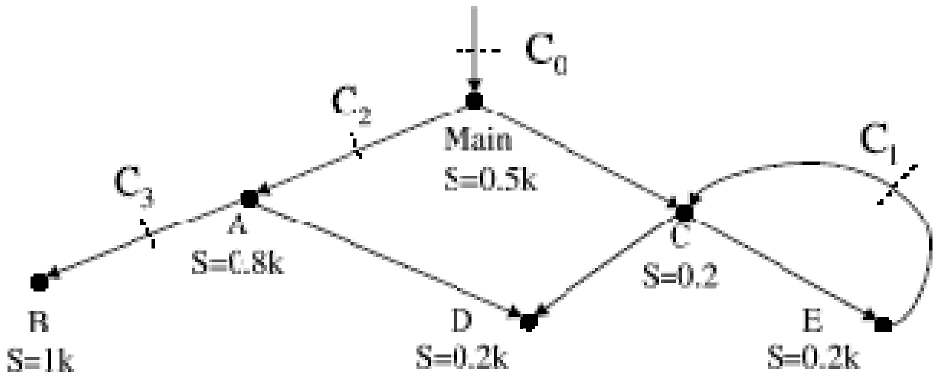
Capriccio

- “Scalable Threads for Internet Services” [von Behren et al. SOSP 2003]
  - Compiler-supported approach
  - User-level only
    - “For now”
  - Introduces **linked stacks & resource-aware scheduler**

Linked Stacks

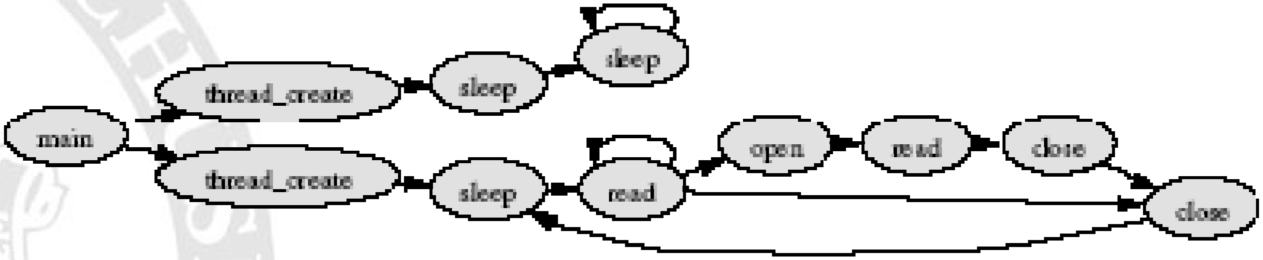
- Uses control-flow graph & compiler-inserted **“checkpoints”** (?) to dynamically allocate **stack chunks**

- Point stack pointer to new chunk before function call
  - Function exit: chunk on free list



- Library code?
  - Programmer-supplied annotations…

Resource-Aware Scheduling

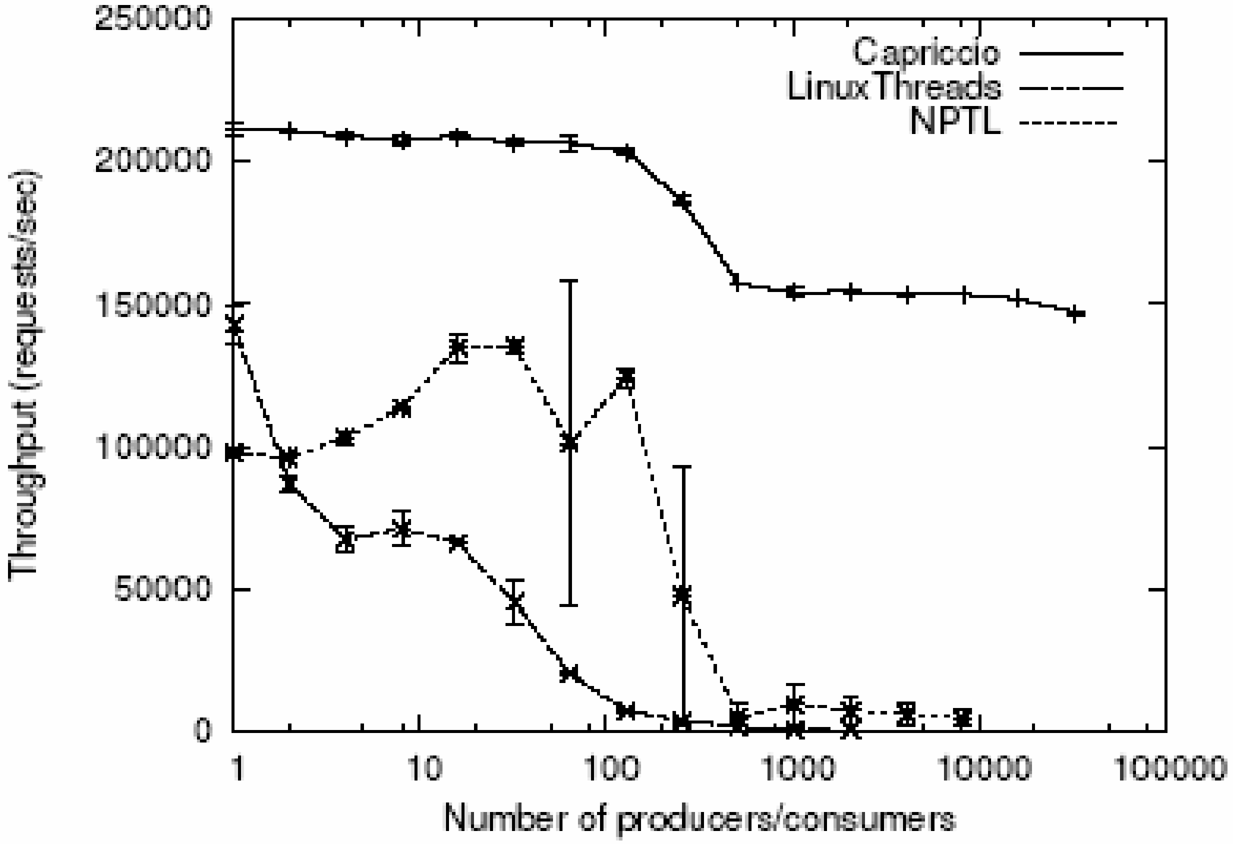


- Capriccio identifies stages by computing **blocking graphs**
  - Edge between consecutive blocking points
  - Built at runtime (nodes = call chains)
  - Tracks runtime, resource usage
- Schedules nodes to maximize utilization
  - Throttle back: schedule nodes that release resources

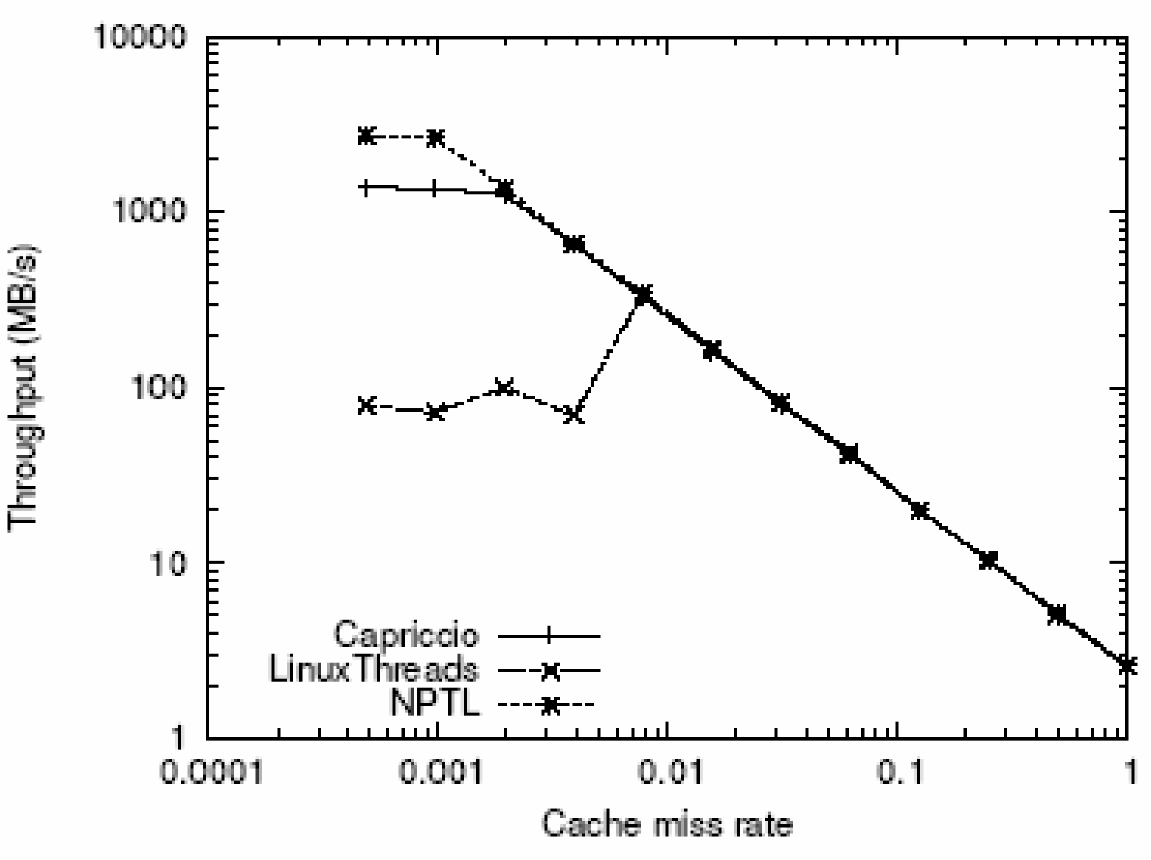
Scheduling: Details

- Separate run queues for each node
  - Determine priority based on predicted resource needs of node, overall utilization
  - Performs **stride scheduling** [Waldspurger & Weihl 95]
    - Assigns **tickets** to nodes
    - **Stride** inversely proportional to #tickets
      - = wait time until next time scheduled
- Tracks CPU, memory consumption, # file descriptors
- Result: doesn’t quite work

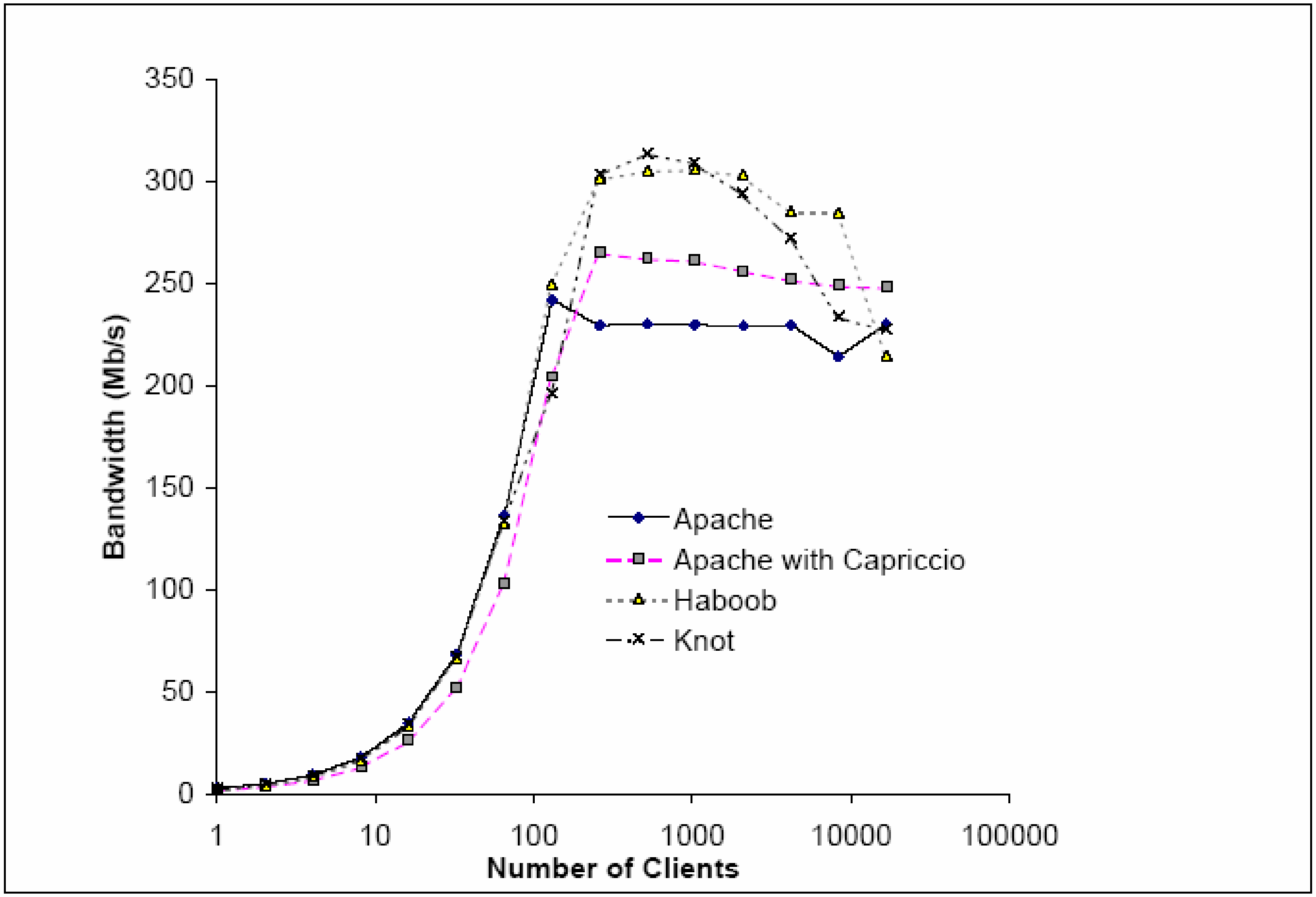
Scalability Results



Scalability with I/O



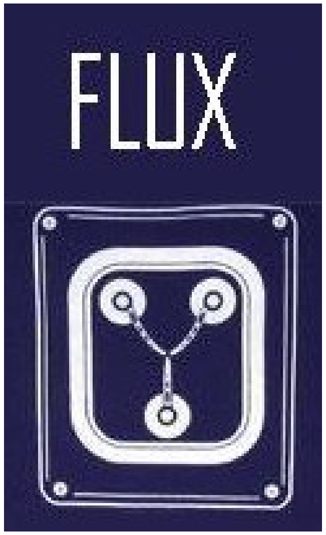
Web Server


Bandwidth (Mb/s)
350
300
250
200
150
100
50
0
1
10
100
1000
10000
100000
Number of Clients
Apache
Apache with Capriccio
Haboob
Knot

Pain of Architectures

- Events hard, threads still suck
- Must commit up front
  - Difficult to change
  - New, better architecture = rewrite code
- Difficult:
  - To program & understand
    - **Interleave server logic with runtime**
  - Identify bottlenecks
  - Predict performance before deployment

Flux: DSL for Servers



- **Ease-of-use**
  - Declarative, implicitly parallel
- **Reuse**
  - Use unmodified code
- **Runtime Independence**
  - Not tied to any model
    - Thread-based, thread pool, event-driven
- **Correctness**
  - No deadlock!
- **Performance Prediction**
- **Bottleneck Analysis**

Flux Servers

- To date, we have built four servers in Flux:
    - Web server
    - BitTorrent “peer”
    - Image scaling server
    - Game server (“tag”)
- Very concise language

Flux Example

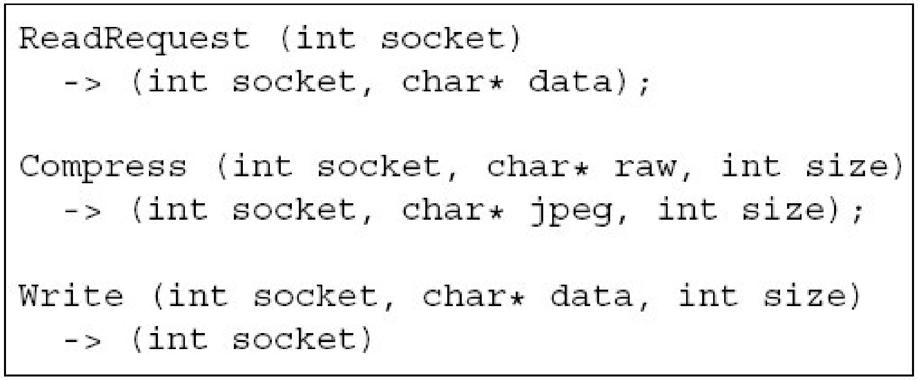
```
Page (int socket) => ();
ReadRequest (int socket)
     => (int socket, bool close, char* request);
Reply (int socket, bool close, int length, char*
content, char* output) => ();
ReadWrite (int socket, bool close, char* file)
     => (int socket, bool close, int length, char*
content, char* output);
Listen () => (int socket);

source Listen => Page;
Page = ReadRequest -> ReadWrite -> Reply;
handle error ReadWrite => FourOhFor;
handle error ReadRequest => BadRequest;
```

Flux Language

- **Concrete Nodes**
  - Correspond to C/C++ implementations
  - Type signatures: outputs follow inputs

- **`ReadRequest`**
  - Parses client input
- **`Compress`**
  - Compresses images
- **`Write`**
  - Outputs compressed image to client



```
ReadRequest (int socket)
  -> (int socket, char* data);

Compress (int socket, char* raw, int size)
  -> (int socket, char* jpeg, int size);

Write (int socket, char* data, int size)
  -> (int socket)
```

Flux Language

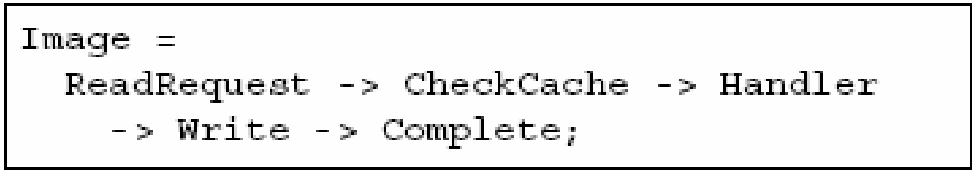
- **Source nodes**
  - Concrete nodes that only produce output
  - Execute inside *infinite loop*

```
source Listen => Image;
```

- **`Listen`**
  - Transfers control to **`Image`** whenever receives connection

Flux Language

- **Abstract Nodes**
  - Captures flow across nodes



```
Image =
  ReadRequest -> CheckCache -> Handler
    -> Write -> Complete;
```

- **`Image`**
  - Checks cache for requested image, handles result, writes output, and completes

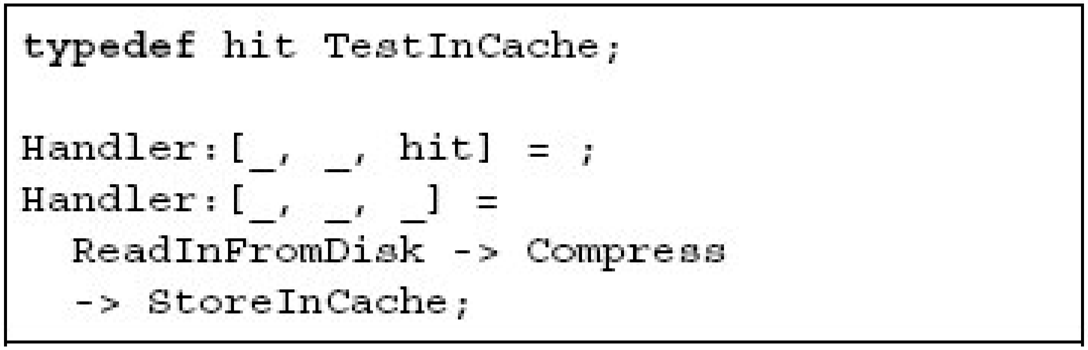
Flux Language

- **Error Paths**
  - If error occurs in node, transfer to error handler
  - Ex: file not found = 404 error

```
handle error ReadInFromDisk -> FourOhFour;
```

Flux Language

- **Predicate Types**
  - “semantic types” in draft
  - Boolean function applied to node’s output
    - Ex: **`hit`** means **`TestInCache`** returned true when applied to argument

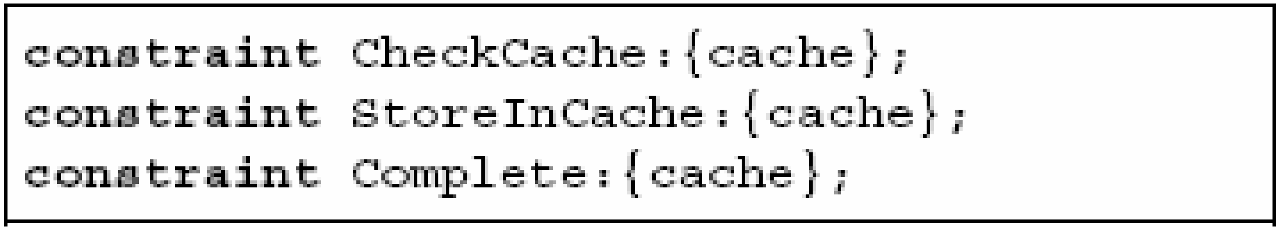


```
typedef hit TestInCache;

Handler:[_, _, hit] = ;
Handler:[_, _, _] =
  ReadInFromDisk -> Compress
  -> StoreInCache;
```

Flux Language

- **Concurrency constraints**
  - *Labels* indicate which nodes cannot execute simultaneously
  - *Readers/Writers:* readers append “?”
    - Default – writers (“!”)
  - *Session constraints*
    - Only applied to particular “sessions”



```
constraint CheckCache:{cache};
constraint StoreInCache:{cache};
constraint Complete:{cache};
```

Concurrency Constraints

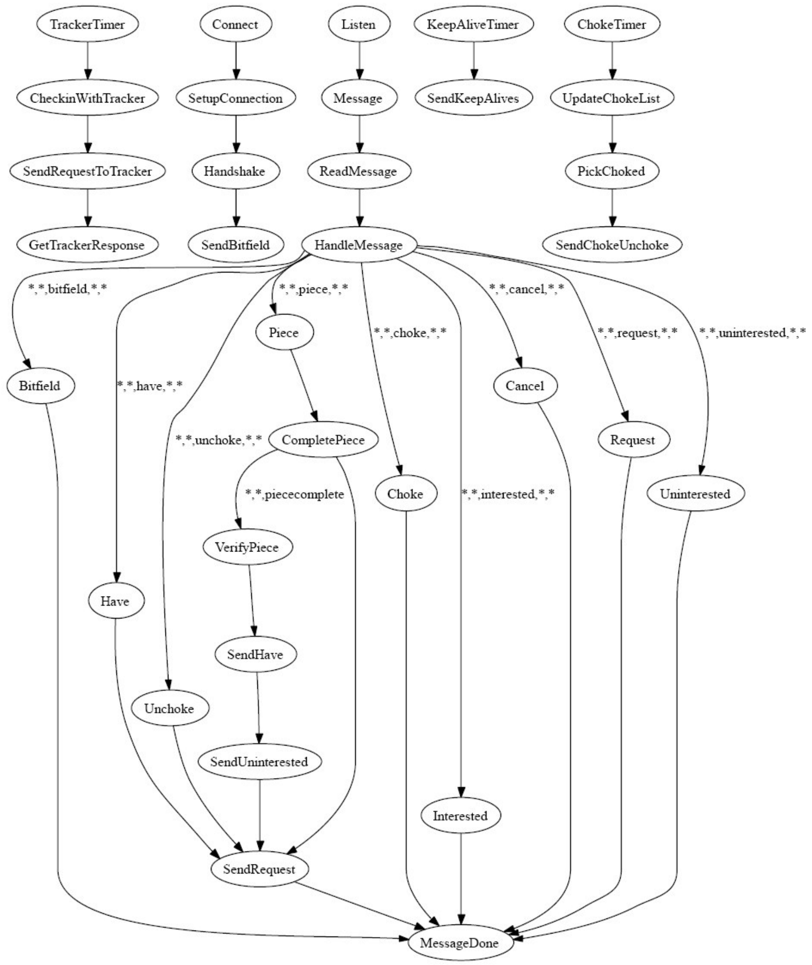
- **Safety**
  - Compiler enforces canonical lock order
  - Reentrant
    - No multiple locking bugs
  - Data flows *acyclic*
    - No deadlock!
    - **Note:** loops inside implementations & implicitly from client

Concurrency Constraints

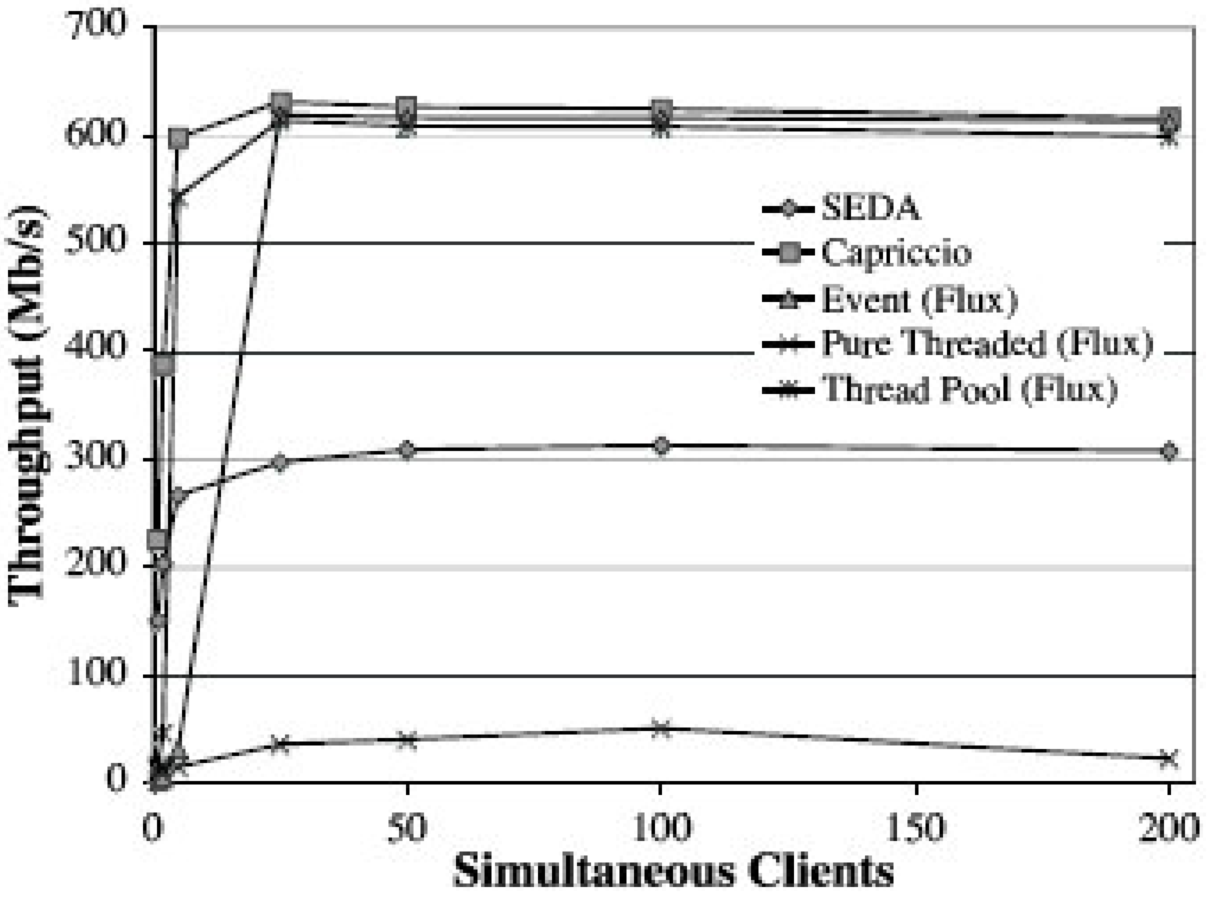
- **Efficiency**
  - Exposing constraints lets compiler generate code specialized for different runtimes
  - Multithreaded – generate locks
  - SPED – no locks required

Complete Flux Program

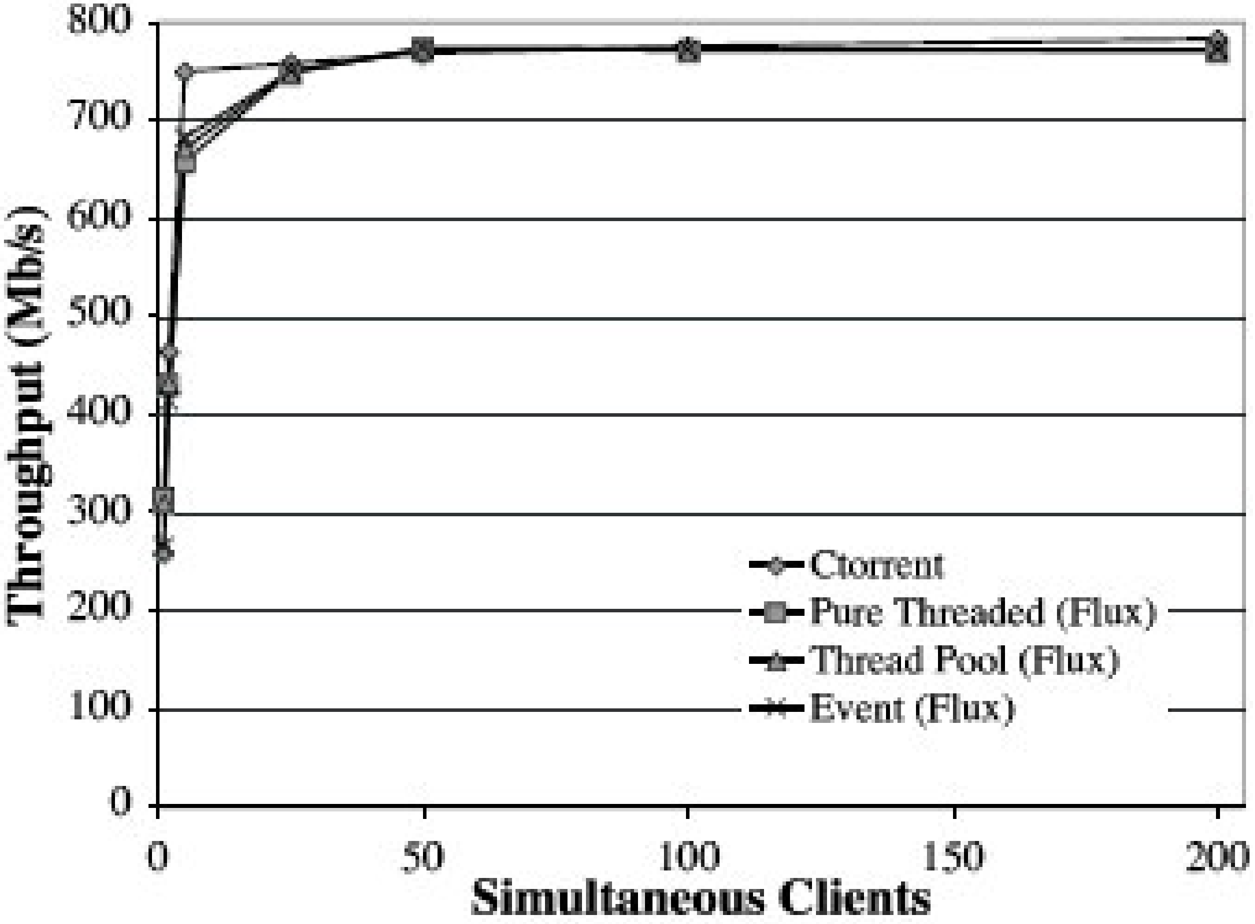
- Automatically generates graphical representation
- BitTorrent example
  - Arcs denote flow
  - Annotations denote types



Web Server Performance

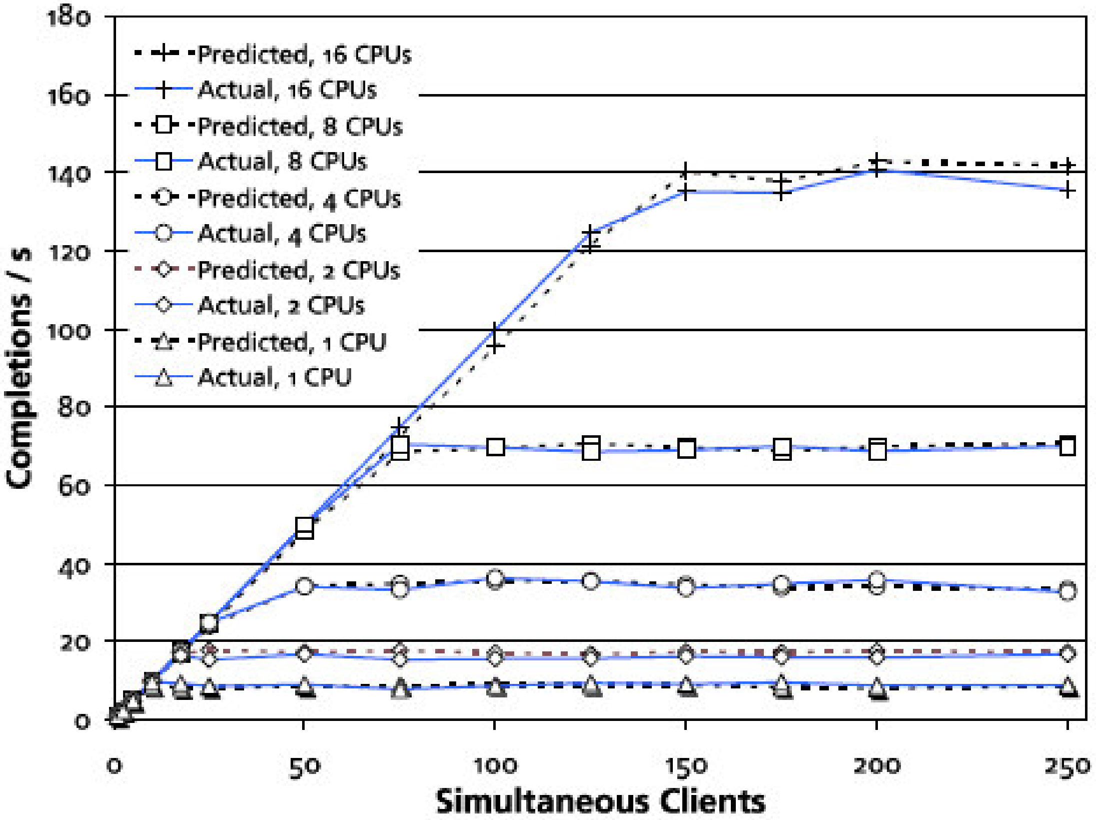


BitTorrent Performance



Performance Prediction

- Generates discrete event simulator
  - Uses parameters from uniprocessor run



The End