The Aesop Language

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Aesop - In Short

- New programming language (+ support libraries)
  - Based on C language with added concurrency and other extensions
  - Designed for implementing distributed network services
  - Aims to maintain sequential flow while programming without requiring sequential execution.
  - Aims to be highly productive.

- Implemented as Source-To-Source translator
  - Translator written in Haskell, injects macro calls into the source.
  - Outputs plain C

- Also provides RPC helper
  - Generates local and remote network and encoding/decoding functions

- Stand-alone distribution
  - Git repository at `git://git.mcs.anl.gov/aesop`
  - Trac (wiki & bug reports) at `http://trac.mcs.anl.gov/project/aesop`

Aesop - Motivation

- Most people prefer writing sequential code (reasoning, algorithms, …)
- Easiest way to have sequential code in a network server is using threads. However
  - Threads can have high overhead (thread stack, context switch, thread creation, locking)
  - Not all device APIs map to a thread model
    (or hard to drive efficiently from multiple threads)
    - Poll/epoll/select
    - MPI_Waitsome/MPI_Waitany

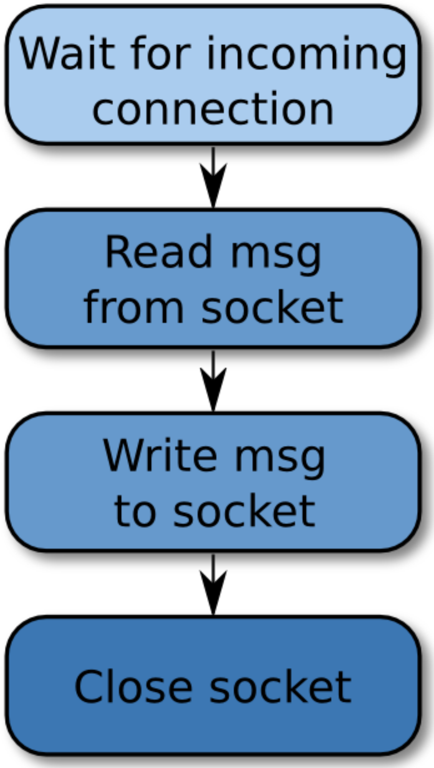
- Consequently, many high-concurrency network services are written in an event-driven manner (memcached, apache, …).

- Unfortunately, writing event-driven code is hard
  - Manual stack management ('stack ripping')
  - Difficult to follow control flow (callback to callback) [debugging!]
  - Cannot call functions that take a significant time to complete ('inversion of control')
  - Running multiple event loops (for multi-core processors)

Example: Echo Server (7/tcp)

(with some processing added in)

Open TCP connection to port 7, server writes back uppercase of data received



```
void handleClient (fd) {
       char buf[];
       read (fd, buf);
       uppercase (buf);
       write (fd, buf);
       close (fd);
}

int main (int argc, char ** args) {
  [...]
  while (true) {
       int fd = accept (sock);
       handleClient (fd); // or thread
  }
}
```

Automatic variables

Linear control flow

Concurrency granularity: thread

Event Version

```
enum { STATE_READ, STATE_WRITE, STATE_CLOSE };
void handleRequest (request * req) {
    switch (req->state) {
        case STATE_READ:
                    read (req->fd, req->buf); state = STATE_WRITE; break;
        case STATE_WRITE;
                    uppercase (req->buf);
                    write (req->fd, req->buf); state = STATE_CLOSE; break;
    }
}
int main (int argc, char ** args) {
    while (true) {
        if (can_accept (socket)) {
          int fd = accept;
          req = malloc (sizeof (request));
          req->fd = fd; req->state = STATE_READ;
          active_requests_add (req);
        }
        req = wait_for_req_ready ();
        if (!handleRequest (req))
           { active_requests_remove(req); close(req->fd); free (req); }
    }
}
```

Inversion of control

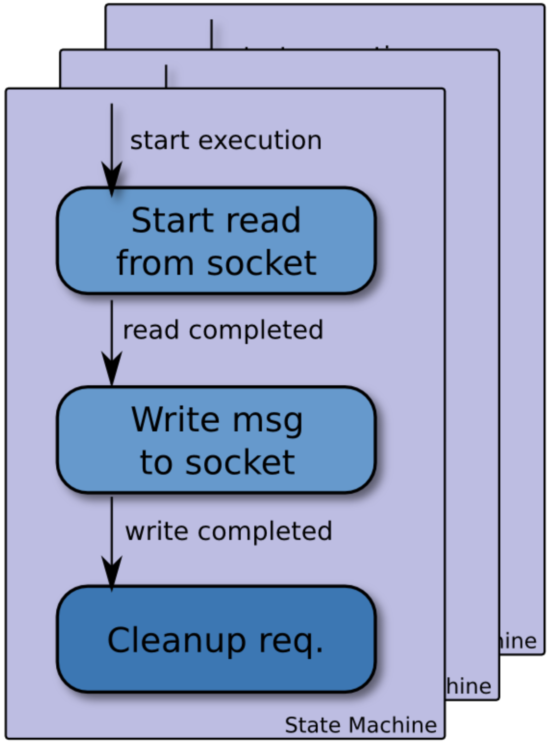
Manual state management

Single event loop

Concurreny: none (or event loop)

PVFS2 State Machine Compiler

- Similar to flex/bison: takes blocks of C code and adds glue than can be automated.
- Simple parser (C blocks are opaque)



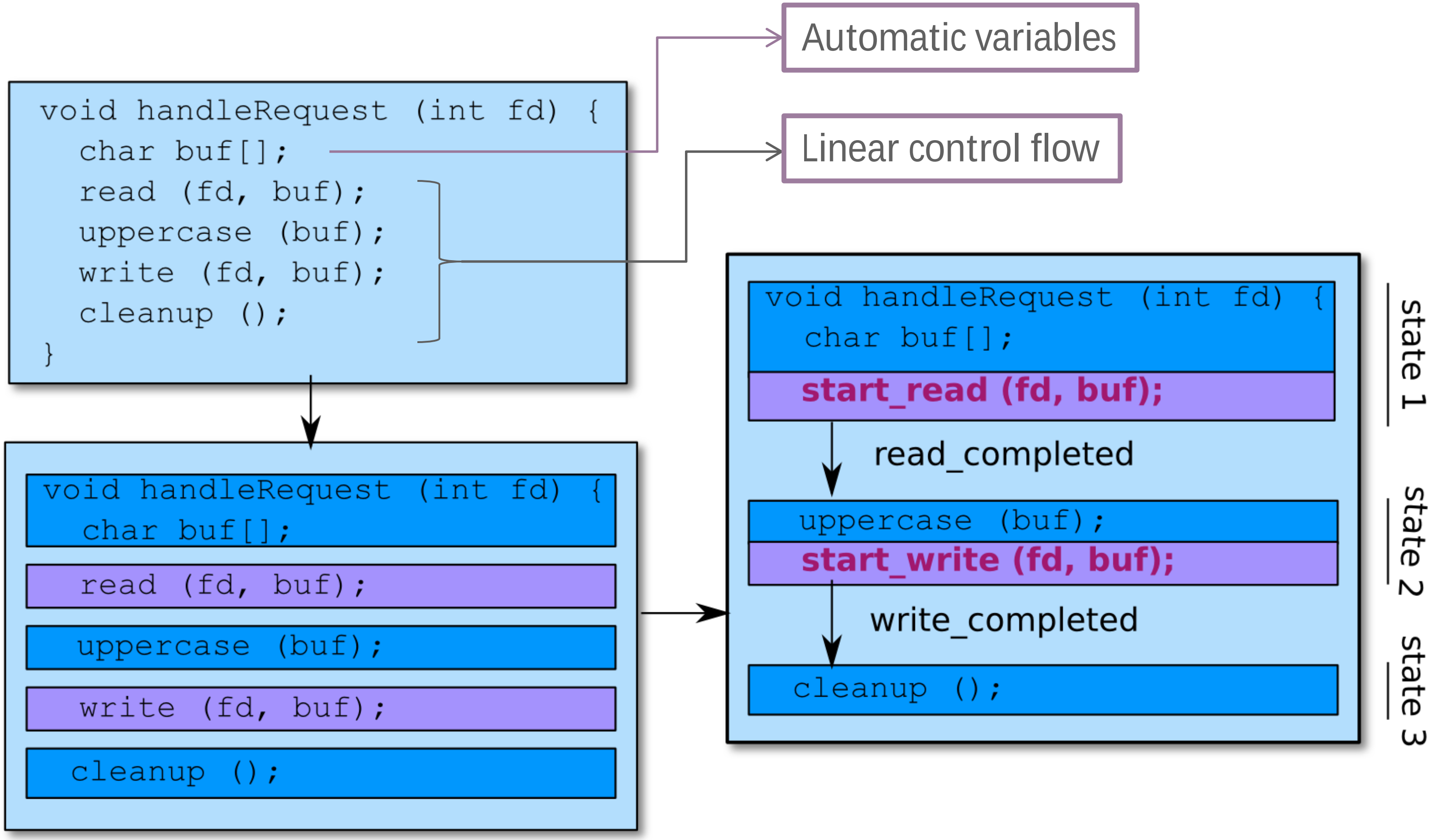
```
machine echo_request {
    state start_read {
      run request_read;        // C function
      default => start_write; // next state
    }
    state start_write {
      run request_write;
      default => close;
     }
    state close {
      run request_cleanup;
      default => terminate;
     }
}
```

- Unified interface required (start, test)
- Restores some of the control flow
- Help with state management

Note: accept code & actual read/write/cleanup code not shown

Aesop

Automatic State Machines



Automatic variables

Linear control flow

```
void handleRequest (int fd) {
  char buf[];
  read (fd, buf);
  uppercase (buf);
  write (fd, buf);
  cleanup ();
}
```

```
void handleRequest (int fd) {
  char buf[];
  read (fd, buf);
  uppercase (buf);
  write (fd, buf);
  cleanup ();
```

```
void handleRequest (int fd) {
  char buf[];
  start_read (fd, buf);
        read_completed
  uppercase (buf);
  start_write (fd, buf);
        write_completed
  cleanup ();
```

state 1

state 2

state 3

Concurrency: none or event loop

Why invent our own programming language?

- Existing Parallel Programming models
  - Focus on optimizing CPU usage
  - Do not offer assistance for handling devices such as network and storage devices.
  - Do not support cancellation
  - Problem partitioning mapped directly to threads
  - Portability might be an issue
- Event driven programming libraries
  - Unify handling of asynchronous operations
  - Require algorithms to be casted into an event-driven form
  - Generally only support single-threaded event loops

Blocking vs Non-Blocking ⚠

- Non-blocking code is cpu bound.
- Blocking code is not cpu bound, meaning that the completion typically depends on some external event.
- Aesop does not enforce correct usage.
- Blocking or non-blocking is a property of a C function (or function pointer)
  - indicated by the `__`***`blocking`*** keyword
  - Visible when declaring function, not when calling function.

Examples:

- Calculating a checksum is not blocking.
- Sleeping for 6 seconds or waiting for an alarm time is blocking.
- Reading or writing from network or disk is blocking.

- Any function calling a blocking function is also blocking.

```
__blocking int aesop_main (int argc, char ** args) { … }
```

The pbranch keyword

- Basic concurrency construct in aesop is the pbranch
- Pbranch creates a C scope
- Pbranches can be executed concurrently with other code
  - Within the pbranch, execution is sequential

Example 1:

```
pprivate int i;
for (i=0; i<100; ++i)
{
   pbranch {
       do_something (i);
       do_something_else ();
   }
}
```

Example 2:

```
{
   pbranch { call1 (); }
   pbranch { call2 (); }
}
```

Private pbranch variables

- Pbranches share variables from the enclosing scope by default
- Use the pprivate variable modifier to give each pbranch a private copy
- Private copy is initialized when entering the pbranch.

Code example

```
pprivate tmp;
pbranch {
             // own copy of tmp
}
pbranch {
             // own copy of tmp
}
```

pbranch synchronization: pwait

The pwait keyword enables synchronizing with the enclosed pbranches.

Example

```
pwait {
   pbranch {                // func_1() might
       func_1 ();           // execute concurrently with
   }                        // func_2();
   pbranch {                // func_2() will not
       func_2 ();           // wait for func1() to
   }                        // complete if it blocks.
}                           // func_3() will not execute
func3 ();                   // until func_1() and
                            // func_2() completed.
```

Note: pbranch without enclosing pwait is possible: lonely pbranch.

Cancelling blocking functions

- One of the major differences between aesop and other concurrency extensions (such as OpenMP) is aesop's support for cancellation.
- pbranches can be cancelled.
  - Cancellation is **`clean': proper cancellation function is automatically called by** aesop. (for example: **`MPI_Cancel`** for **`MPI_Recv`**, **`aio_cancel`** for **`aio_read`**, **…)**

Example: cancelling operation after timeout (some error tracking omitted)

```
pwait {
        pbranch {
                do_some_processing ();    // non-blocking function
                send_query ();            // blocking function
                receive_response ();       // blocking function
                aesop_cancel_branches ();
        }
        pbranch {
                aesop_timer (10);
                aesop_cancel_branches ();
   }
}
```

Resources

- So far, functions were blocking because they called one or more blocking functions.
- A resource is a collection of one or more (public) blocking functions, with the difference that those blocking functions do not call any other blocking functions.
  - Resource functions look and behave exactly like all other functions.
  - The innermost blocking function in a call-graph is always a resource function.
- Resources can (and typically do) also contain regular (non-blocking) functions.
- Resources also contain some special aesop-internal functions for testing, polling, context handling and cancellation.
- Resources are written in plain C

Example resources:

- Timer (in default aesop distribution)
- Signal
- socket

Some Notes

- Aesop does not require or create threads: it does not dictate concurrency model
  - Resources might use threads internally
  - Aesop is thread-safe (could use multiple threads to drive aesop)

- Resources can choose the most efficient driving model (threads, poll) (for a given system) without affecting the use of the resource.

- There are no explicit state machines
  - Blocking functions are pulled apart into segments containing no blocking calls
    - Variables are moved from the stack to the heap (and references adjusted)
  - Non-blocking functions not modified

- Easiest mental model for aesop code: lightweight cooperative threads (with blocking function possible context switch point)

Status

- Stand-alone source code distribution of Aesop development environment for use in other storage projects. Documentation on how to install and how to use Aesop.

- Aesop is ready for use
  - Triton (storage system) is written completely in aesop
  - Collection of resources available
  - Own repo / bug tracker `[git://git.mcs.anl.gov/aesop]`
  - Passed performance requirements (more in a moment)

- Places where Aesop can be improved
  - Some minor language bugs
    - Workarounds generally possible
  - Compilation speed
  - Debugging
    - Using preprocessor directives to link to original source, but no debugger supports stepping through the logical control flow.

Productivity

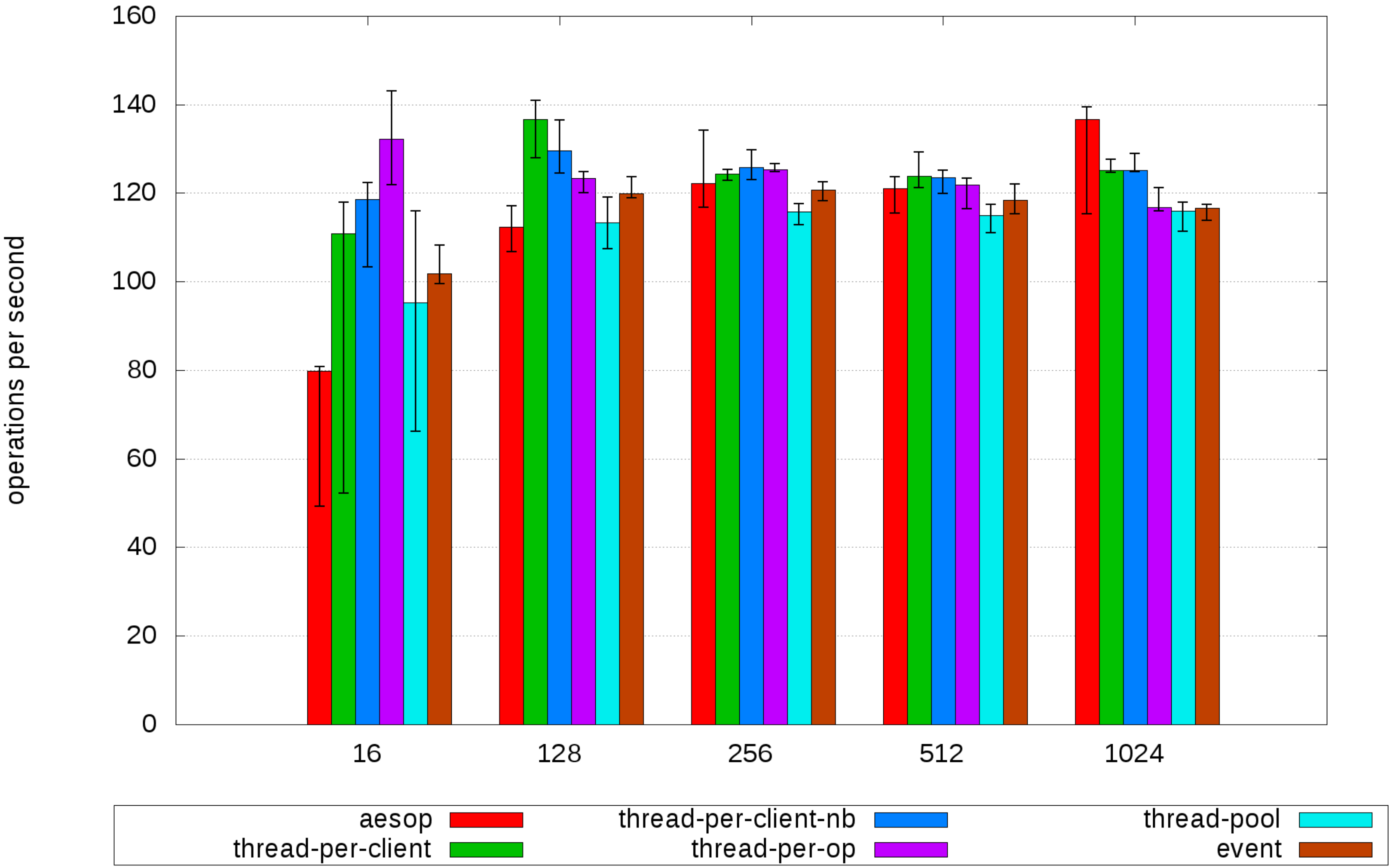
Implemented simple server listening on a TCP socket and responding to one or more client requests, optionally storing or retrieving data from disk.

	CC	Mod. CC	SLOC
Aesop	16	11	179
Thread per client	17	12	182
Thread per op	22	17	249
Threadpool	32	26	313
Event	28	23	341

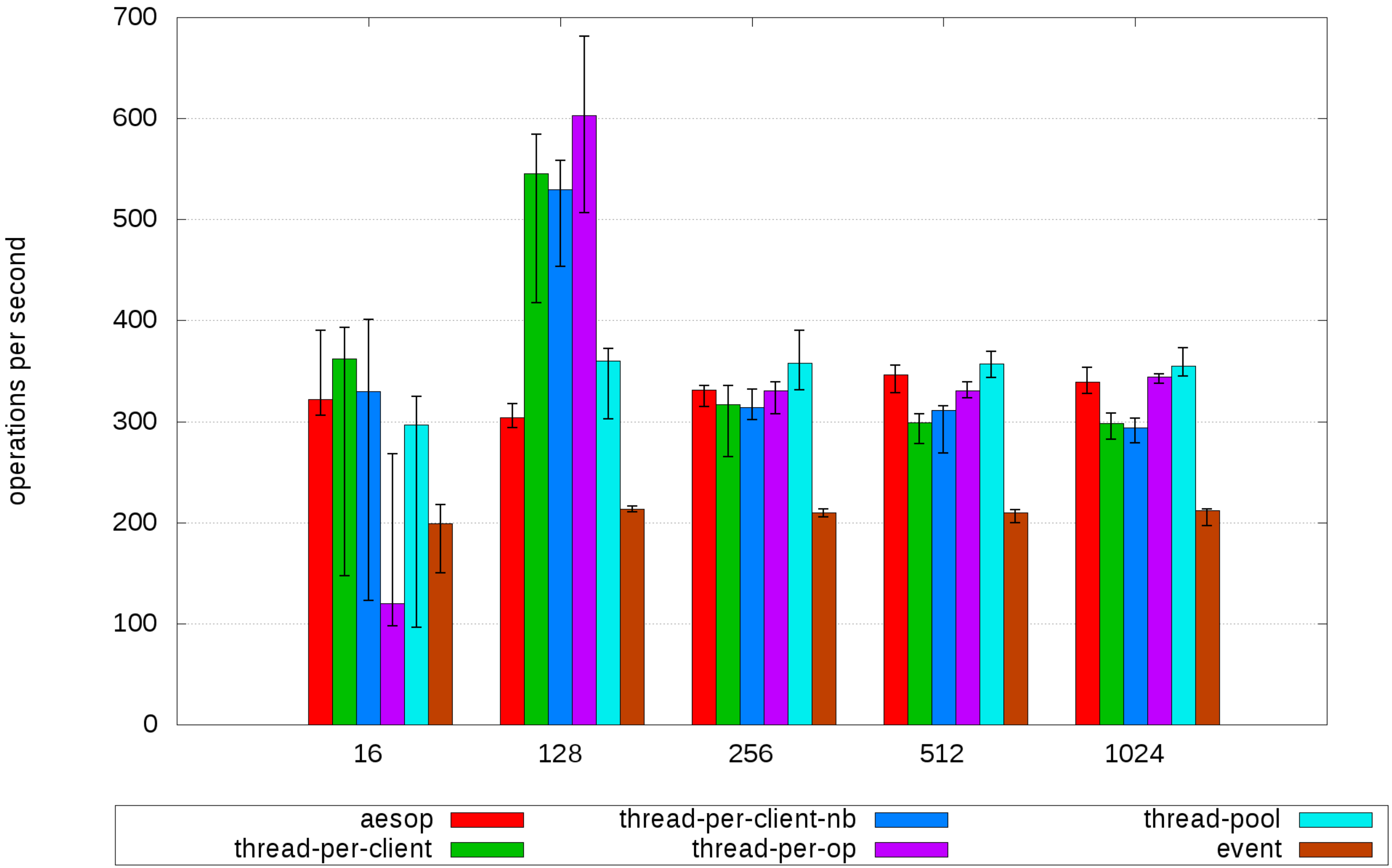
CC: McCabe Cyclomatic Complexity (CC),
Mod. CC: Modified McCabe Cyclomatic Complexity (mod. CC)
SLOC: Source Lines of Code (SLOC).

Note: no error handling, ignoring shared definitions, not using cancellation

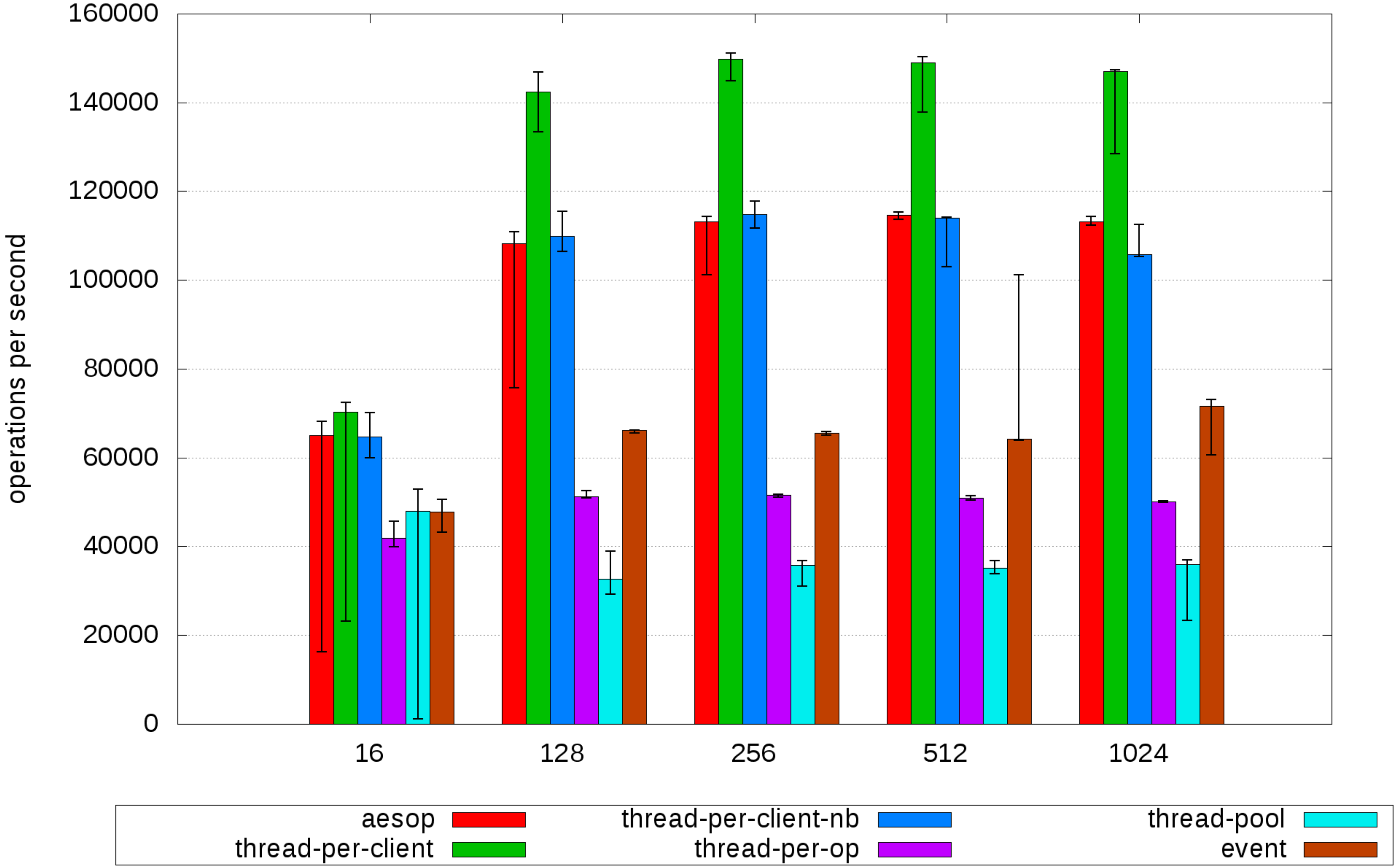
Performance (Write)



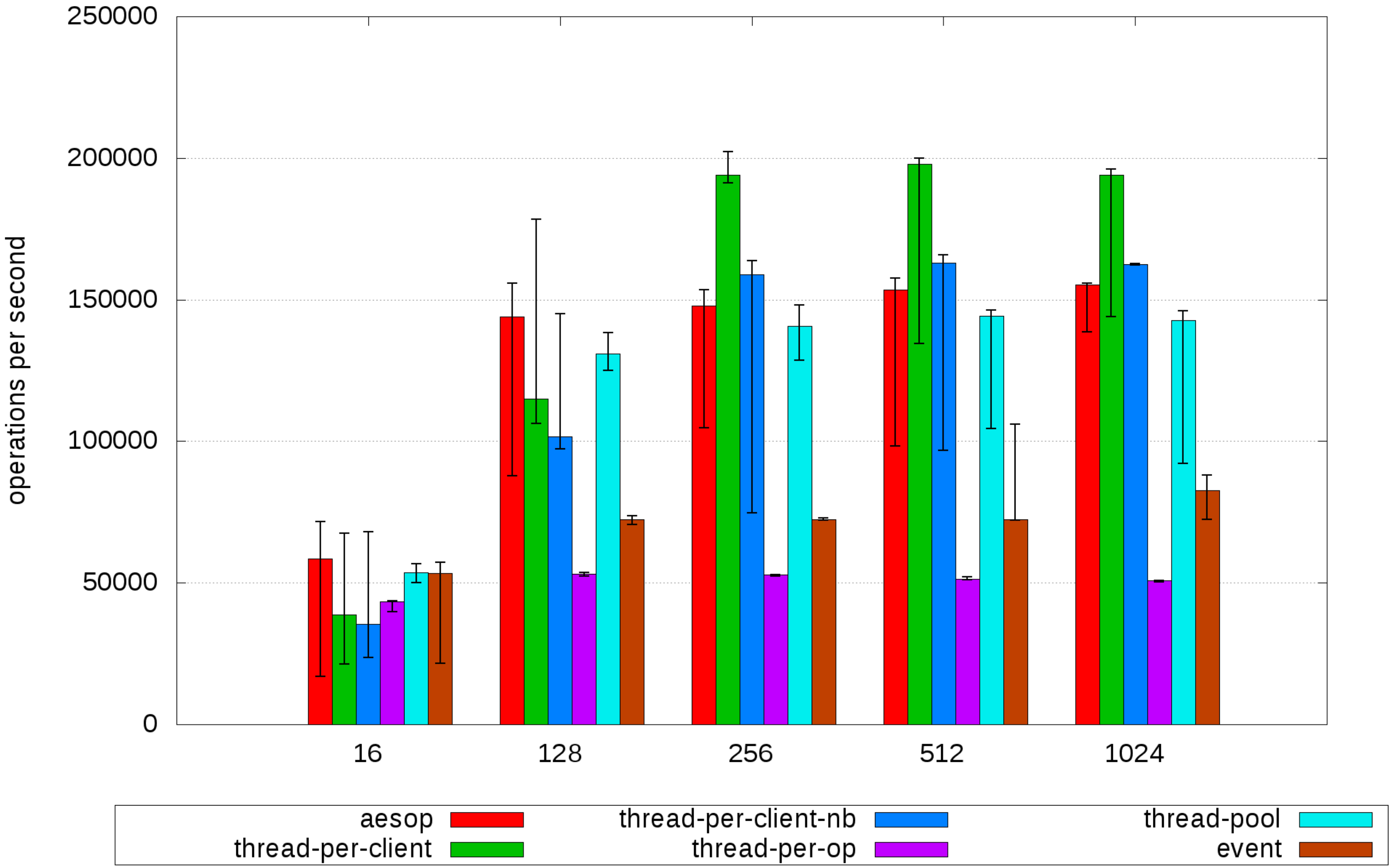
Performance (Read)



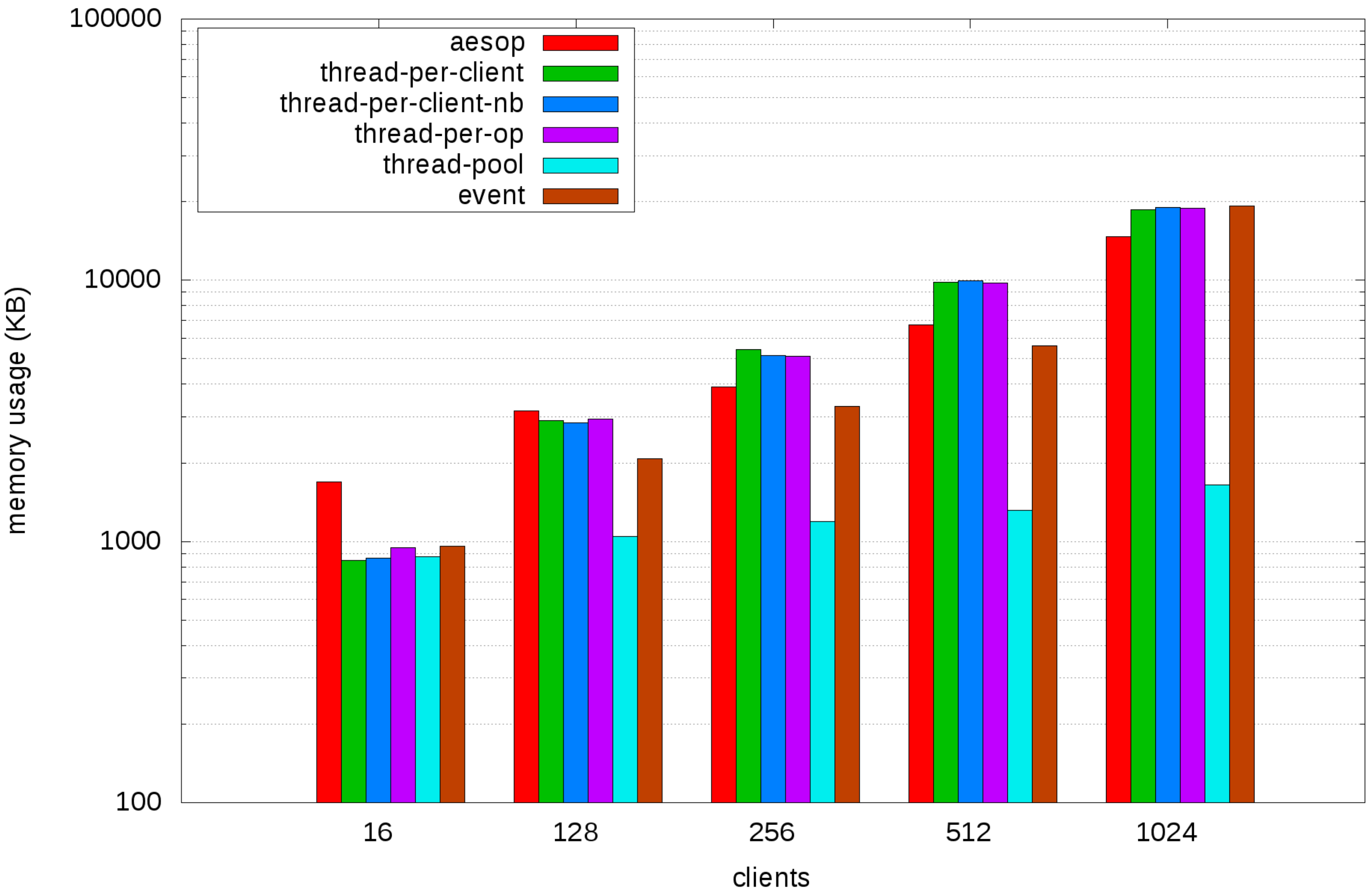
Performance (Write-Null)



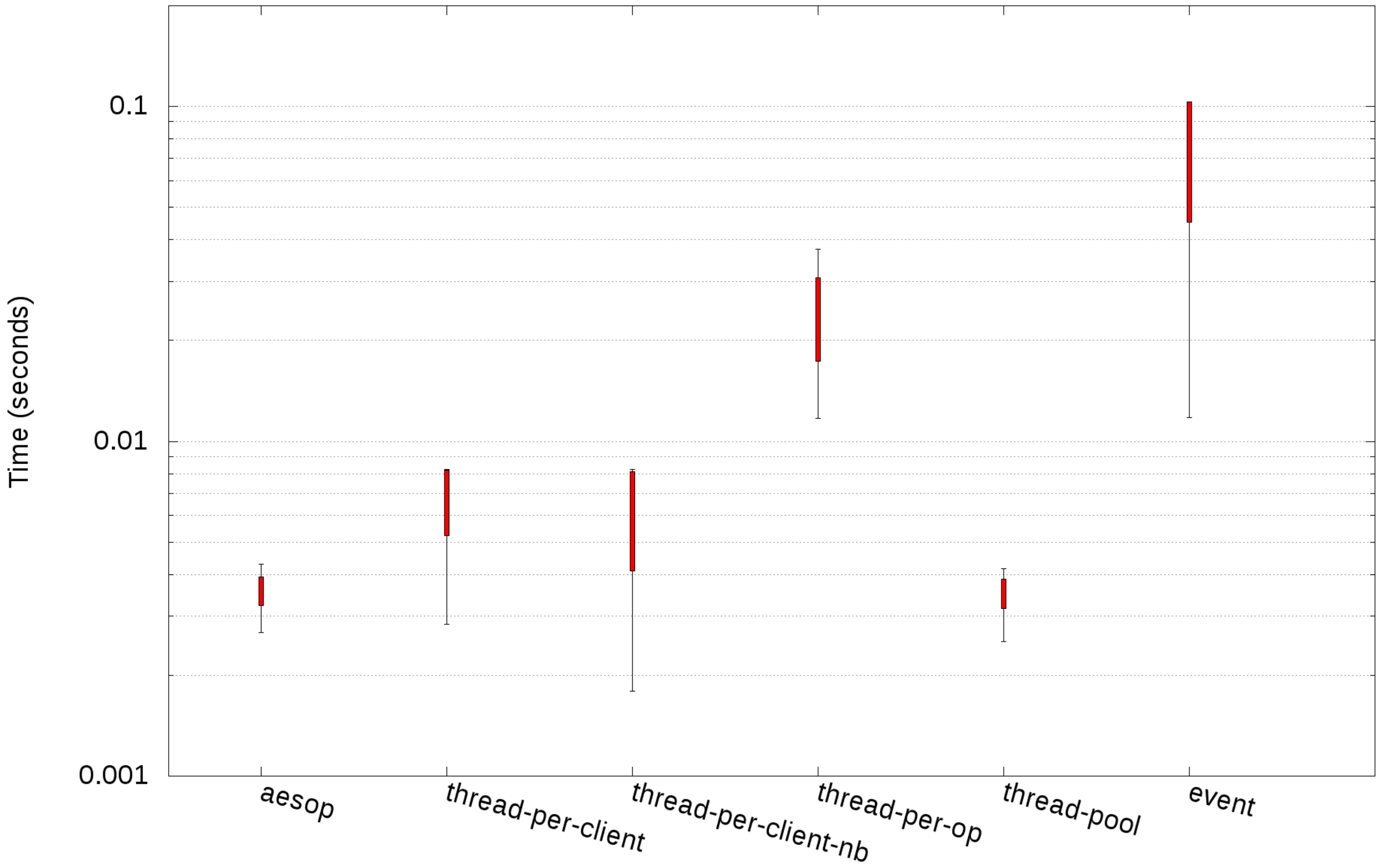
Performance (Read-Null)



Max Memory Usage (write)



Response Time (write, 1024 clients)



Aesop: Summary

- Concurrency extension to the C programming language
- Takes normal C code and detects blocking function calls
- Current implementation creates (implicit) state machine code and writes the boilerplate code; Isolates algorithm from concurrency model.
- Lowers the bar for writing high-performance network servers (for example, can convert sequential into event-driven)
- Fully C compatible: important for reusing existing code and interfacing with low-level OS layers

… with some added features thrown in:

- Concurrent & decoupled execution
- Cancellation
- RPC code generator

Conclusion

Many people are working on Aesop:

- Phil Carns, Kevin Harms, Dries Kimpe, Sam Lang, Rob Ross, Justin Wozniak

Further Reading:

- Code repository: http://git.mcs.anl.gov/aesop
- Documentation, Installation instructions & Bug tracking: http://trac.mcs.anl.gov/projects/aesop

Questions/Remarks?