# Revisiting the Issue of Performance Enhancement of Discrete Event Simulation Software [1]

Alex Bahouth, Steven Crites, Norman Matloff and Todd Williamson
Department of Computer Science
University of California at Davis
Davis, CA 95616 USA
matloff@cs.ucdavis.edu

[1]We wish to thank Victor Castillo and the Lawrence Livermore National Laboratory for supporting this research.

This presentation is produced using C. Campani's Beamer LaTeX class.
See `http://heather.cs.ucdavis.edu/~matloff/beamer.html` for a quick tutorial.
*Disclaimer: Our slides here won't show off what Beamer can do. Sorry. :-)*

# Issues Addressed in This Paper

- Interpreted languages (Java, Python) now popular for DES

# Issues Addressed in This Paper

- Interpreted languages (Java, Python) now popular for DES
- Interpreted languages are slow.

# Issues Addressed in This Paper

- Interpreted languages (Java, Python) now popular for DES
- Interpreted languages are slow.
- DES literature mainly algorithm-centric.

# Issues Addressed in This Paper

- Interpreted languages (Java, Python) now popular for DES
- Interpreted languages are slow.
- DES literature mainly algorithm-centric.
- What can be done specifically for interpreted languages?

# Issues Addressed in This Paper

- Interpreted languages (Java, Python) now popular for DES
- Interpreted languages are slow.
- DES literature mainly algorithm-centric.
- What can be done specifically for interpreted languages?
- What can be done for systems considerations, e.g. VM?

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

- Written by Klaus Muller and Tony Vignaux.

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

- Written by Klaus Muller and Tony Vignaux.
- I have developed an online DES course based on SimPy, available at `heather.cs.ucdavis.edu/~matloff/simcourse.html`.

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

- Written by Klaus Muller and Tony Vignaux.
- I have developed an online DES course based on SimPy, available at `heather.cs.ucdavis.edu/~matloff/simcourse.html`.
- SimPy uses Python:

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

- Written by Klaus Muller and Tony Vignaux.
- I have developed an online DES course based on SimPy, available at `heather.cs.ucdavis.edu/~matloff/simcourse.html`.
- SimPy uses Python:
  - Lots of high-level Python constructs make programming much easier.

# Case Study: SimPy

Our investigation took the form of a case study: enhancing the peformance of the SimPy DES language.
About SimPy:

- Written by Klaus Muller and Tony Vignaux.
- I have developed an online DES course based on SimPy, available at `heather.cs.ucdavis.edu/~matloff/simcourse.html`.
- SimPy uses Python:
  - Lots of high-level Python constructs make programming much easier.
  - Python *generator* construct used by SimPy to set up coroutines, i.e. non-preemptive threads.

# Sample SimPy Code

# Sample SimPy Code

- Machine repair, several machines.

# Sample SimPy Code

- Machine repair, several machines.
- Have class **MachineClass**, with member variables such as **UpTime**, etc.

# Sample SimPy Code

- Machine repair, several machines.
- Have class **MachineClass**, with member variables such as **UpTime**, etc.
- Each class has a member function **Run()** which simulates one machine.

# Sample Run() Function

```
def Run(self):
  while 1:
    self.StartUpTime = SimPy.Simulation.now()
    # hold for up time
    UpTime = G.Rnd.expovariate(MachineClass.UpRate)
    yield SimPy.Simulation.hold,self,UpTime
    # update up time total
    MachineClass.TotalUpTime +=
      SimPy.Simulation.now() - self.StartUpTime
    RepairTime = G.Rnd.expovariate(MachineClass.RepairRate)
    # hold for repair time
    yield SimPy.Simulation.hold,self,RepairTime
```

# Sample Run() Function

```
def Run(self):
  while 1:
    self.StartUpTime = SimPy.Simulation.now()
    # hold for up time
    UpTime = G.Rnd.expovariate(MachineClass.UpRate)
    yield SimPy.Simulation.hold,self,UpTime
    # update up time total
    MachineClass.TotalUpTime +=
      SimPy.Simulation.now() - self.StartUpTime
    RepairTime = G.Rnd.expovariate(MachineClass.RepairRate)
    # hold for repair time
    yield SimPy.Simulation.hold,self,RepairTime
```

The yield actually does yield the processor.

# Sample Run() Function

```
def Run(self):
  while 1:
    self.StartUpTime = SimPy.Simulation.now()
    # hold for up time
    UpTime = G.Rnd.expovariate(MachineClass.UpRate)
    yield SimPy.Simulation.hold,self,UpTime
    # update up time total
    MachineClass.TotalUpTime +=
      SimPy.Simulation.now() - self.StartUpTime
    RepairTime = G.Rnd.expovariate(MachineClass.RepairRate)
    # hold for repair time
    yield SimPy.Simulation.hold,self,RepairTime
```

The yield actually does yield the processor. But yield is a coroutine release—next time this function runs, it resumes after the yield.

# SimPy Data Structures

- Assume for simplicity no tied event times.

# SimPy Data Structures

- Assume for simplicity no tied event times.
- The Python list **timestamps** stores all event times, in ascending order. e.g. to determine the earliest scheduled event.

# SimPy Data Structures

- Assume for simplicity no tied event times.
- The Python list **timestamps** stores all event times, in ascending order. e.g. to determine the earliest scheduled event.
  *A Python list is not an array!* One may insert and delete elements, with the corresponding overhead of shifting data.

# SimPy Data Structures

- Assume for simplicity no tied event times.
- The Python list **timestamps** stores all event times, in ascending order. e.g. to determine the earliest scheduled event.
  *A Python list is not an array!* One may insert and delete elements, with the corresponding overhead of shifting data.
- The actual events are in a Python *dictionary* (associative array) named **events**.
  Python dictionaries are implemented as hash tables, reasonably fast.

# SimPy Queue Operations

# SimPy Queue Operations

When a new event is created at time t, then these operations occur:

(i) add t to list **timestamps**

(ii) add event to dictionary **events**

# SimPy Queue Operations

When a new event is created at time t, then these operations occur:

(i) add t to list **timestamps**

(ii) add event to dictionary **events**

Step (i) makes use of Python's **bisect()** function, which performs bisection sort.

# SimPy Queue Operations

When a new event is created at time t, then these operations occur:

(i) add t to list **timestamps**

(ii) add event to dictionary **events**

Step (i) makes use of Python's **bisect()** function, which performs bisection sort.
That would appear to be O(log n) time, for an n-item event list.
Due to SimPy's use of Python's list structure, it is actually O(n), due to right-shifting of the data.

# SimPy Dequeue Operations

# SimPy Dequeue Operations

When the next event is executed, these operations occur:

(iii) remove head of list **timestamps**, time t

(iv) reactivate (invoke Python iterator for) **Run()** function for event of time t in dictionary **events**

# SimPy Dequeue Operations

When the next event is executed, these operations occur:

(iii) remove head of list **timestamps**, time t

(iv) reactivate (invoke Python iterator for) **Run()** function for event of time t in dictionary **events**

Again, what would appear to be an O(1) event is actually O(n).

# Summary of Sources of SimPy Slowness

# Summary of Sources of SimPy Slowness

- Dictionary (smaller problem).

# Summary of Sources of SimPy Slowness

- Dictionary (smaller problem).
- O(n) insert operation instead of O(log n) (big problem).

# Summary of Sources of SimPy Slowness

- Dictionary (smaller problem).
- O(n) insert operation instead of O(log n) (big problem).
- O(n) dequeue operation instead of O(1) (big problem).

# Summary of Sources of SimPy Slowness

- Dictionary (smaller problem).
- O(n) insert operation instead of O(log n) (big problem).
- O(n) dequeue operation instead of O(1) (big problem).
- Possible VM issues.

# Our Solutions

# Our Solutions

- Remove dictionary entirely.

# Our Solutions

- Remove dictionary entirely.
- Rewrite core event-list operations in C for speed.

# Our Solutions

- Remove dictionary entirely.
- Rewrite core event-list operations in C for speed.
- SWIG forms the “glue.”

# Our Solutions

- Remove dictionary entirely.
- Rewrite core event-list operations in C for speed.
- SWIG forms the “glue.”
- Rethink event-list algorithms.

# Removal of Events Dictionary

# Removal of Events Dictionary

- Incorporate into the **timestamps** list, so list elements are now of the form `(time, event)` instead of `(time)`.

# Removal of Events Dictionary

- Incorporate into the **timestamps** list, so list elements are now of the form `(time, event)` instead of `(time)`.
- The **bisect()** operation still works!

# Removal of Events Dictionary

- Incorporate into the **timestamps** list, so list elements are now of the form `(time, event)` instead of `(time)`.
- The **bisect()** operation still works!
- Needed to overload Python's $<$ operator.

# Rewriting Event List Ops in C for Speed

# Rewriting Event List Ops in C for Speed

- "Best of both worlds"—core runs in C, but apps programmer still writes in high-level Python.

# Rewriting Event List Ops in C for Speed

- "Best of both worlds"—core runs in C, but apps programmer still writes in high-level Python.
- Used SWIG Python/C "glue" tool. (Available for Java etc. too.)

# Rewriting Event List Ops in C for Speed

- "Best of both worlds"—core runs in C, but apps programmer still writes in high-level Python.
- Used SWIG Python/C "glue" tool. (Available for Java etc. too.)
- SWIG very easy to learn, use.

# Rewriting Event List Ops in C for Speed

- "Best of both worlds"—core runs in C, but apps programmer still writes in high-level Python.
- Used SWIG Python/C "glue" tool. (Available for Java etc. too.)
- SWIG very easy to learn, use.
- We did have to be careful regarding reference counts.

# Rethinking Event List Algorithms

# Rethinking Event List Algorithms

- Lots of work in the past.

# Rethinking Event List Algorithms

- Lots of work in the past.
- However, most algorithm-centric.

# Rethinking Event List Algorithms

- Lots of work in the past.
- However, most algorithm-centric.
- Typically "simulations of simulation," not timing of actual programs.

# Rethinking Event List Algorithms

- Lots of work in the past.
- However, most algorithm-centric.
- Typically "simulations of simulation," not timing of actual programs.
- No consideration of systems issues, e.g. VM.

# Empirical Evaluation

Tested many different modifications of SimPy

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)
- SimPy with original event structures retained (though no dictionary) but operations implemented in C (PQArr)

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)
- SimPy with original event structures retained (though no dictionary) but operations implemented in C (PQArr)
- SimPy modified to use C-language calendar queue (CQ)

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)
- SimPy with original event structures retained (though no dictionary) but operations implemented in C (PQArr)
- SimPy modified to use C-language calendar queue (CQ)
- SimPy modified to use C-language splay tree (Splay)

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)
- SimPy with original event structures retained (though no dictionary) but operations implemented in C (PQArr)
- SimPy modified to use C-language calendar queue (CQ)
- SimPy modified to use C-language splay tree (Splay)
- Many others were tried but found to be noncompetitive.

# Empirical Evaluation

Tested many different modifications of SimPy

- original SimPy (SimPy)
- SimPy with dictionary removed, but still all-Python implementation (SimPyND)
- SimPy with original event structures retained (though no dictionary) but operations implemented in C (PQArr)
- SimPy modified to use C-language calendar queue (CQ)
- SimPy modified to use C-language splay tree (Splay)
- Many others were tried but found to be noncompetitive.

Testbeds:

- Call center application. Indexed by arrival rates.
- Hold Model. Indexed by coeff. of var. of service times.

# Results

Summary, from fastest to slowest:

# Results

Summary, from fastest to slowest:
$CQ \approx$

# Results

Summary, from fastest to slowest:
$CQ \approx PQArr >$

# Results

Summary, from fastest to slowest:
$CQ \approx PQArr > SplayTree >$

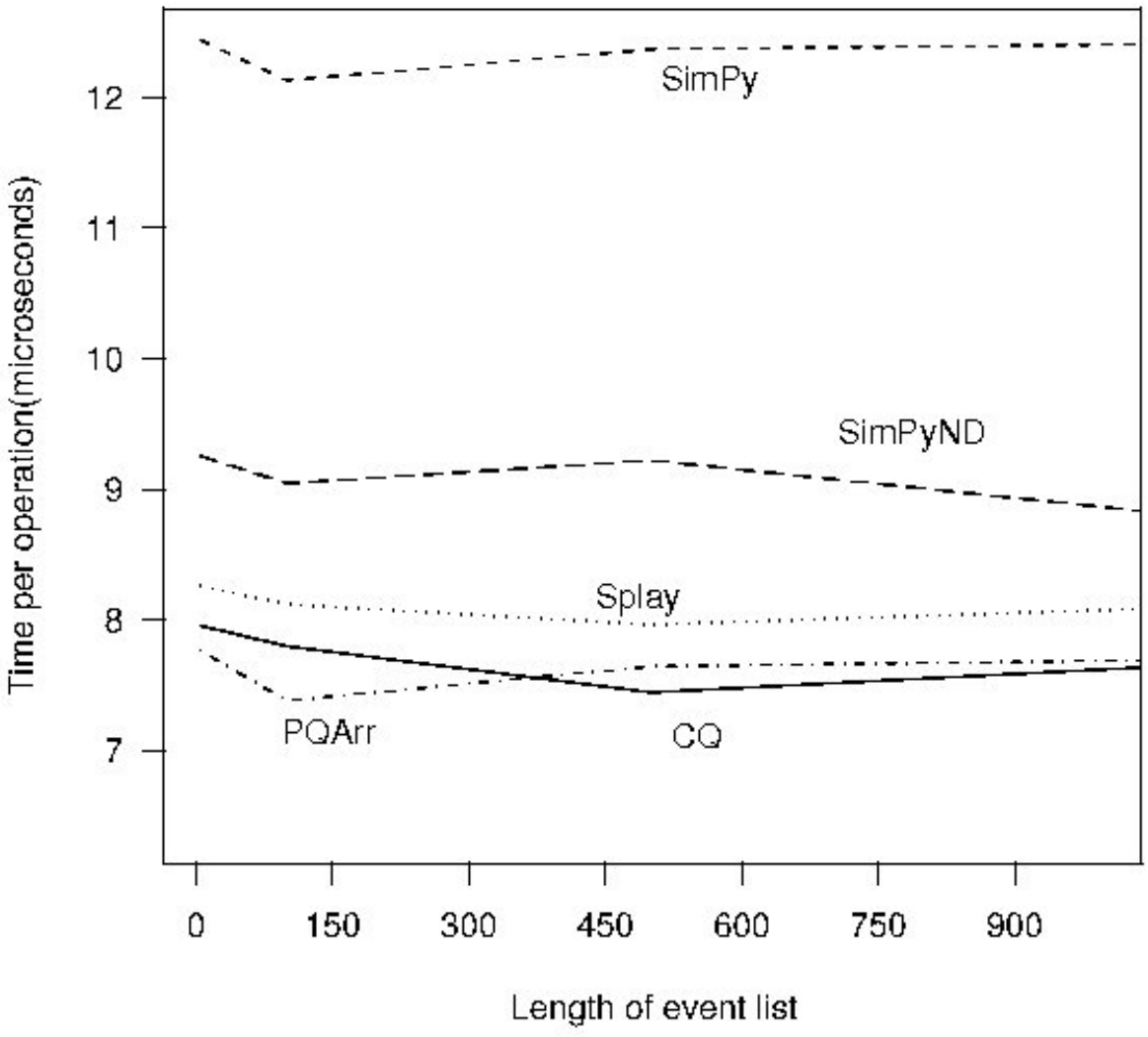
# Results

Summary, from fastest to slowest:
$CQ \approx PQArr > SplayTree > SimPyND >$

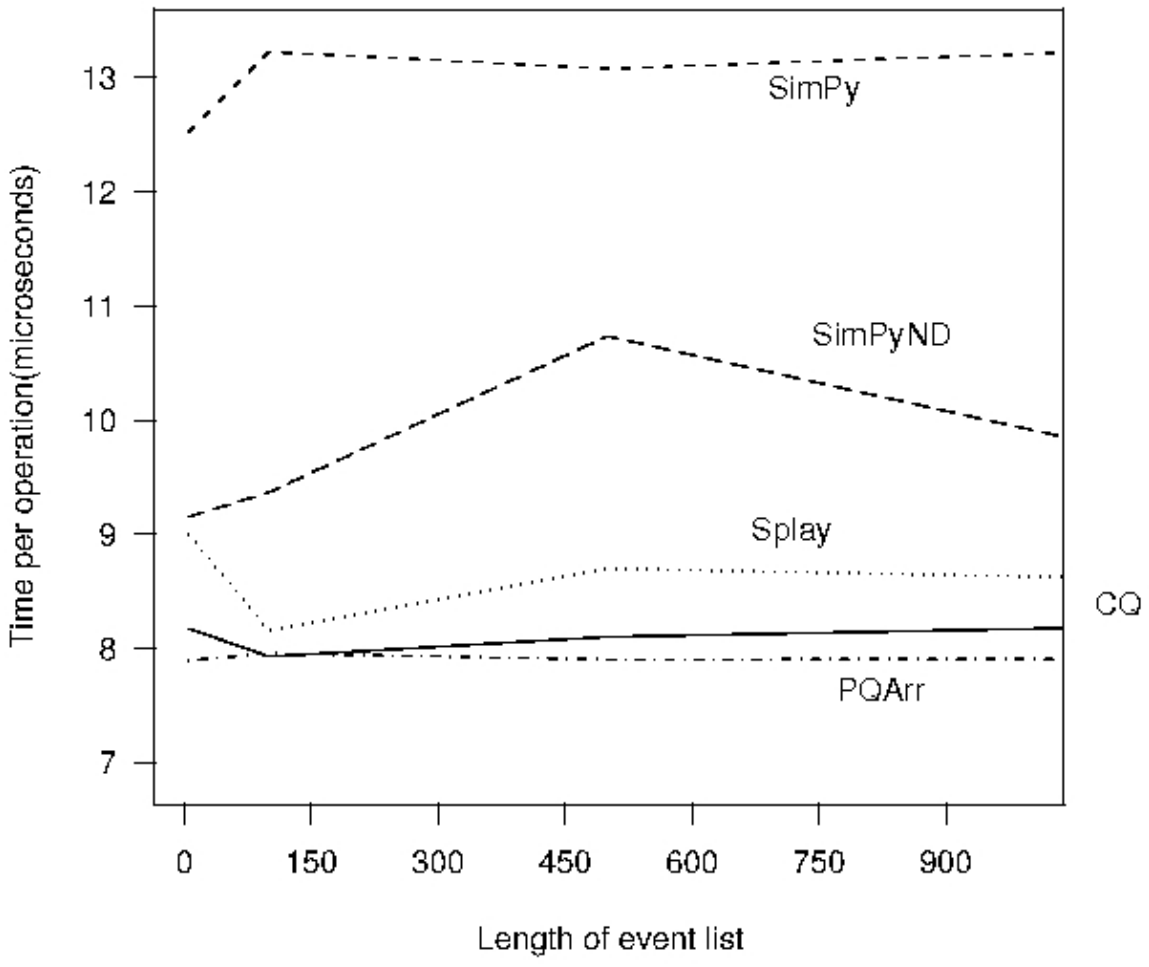
# Results

Summary, from fastest to slowest:
$CQ \approx PQArr > SplayTree > SimPyND > SimPy$

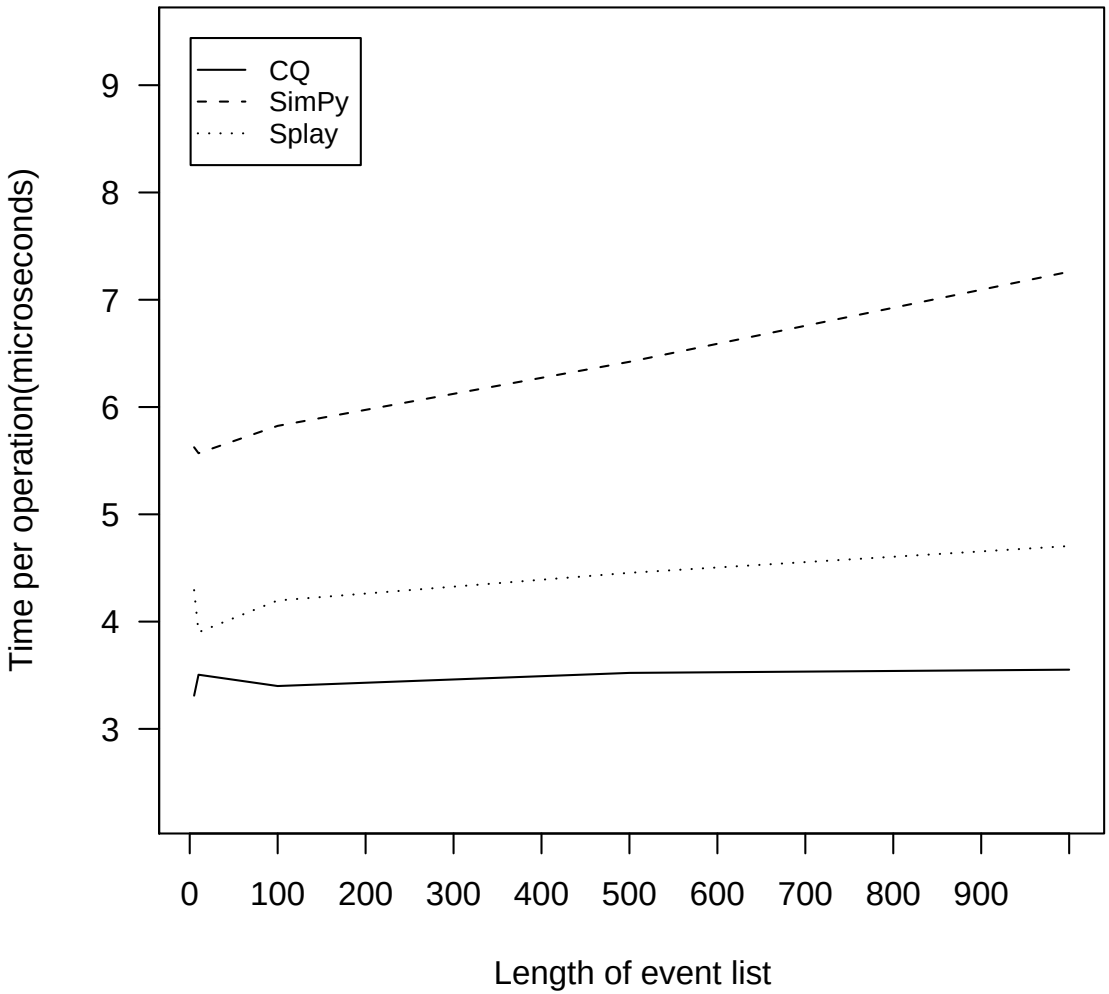
# Call Center Times Per Op, Lower Traffic



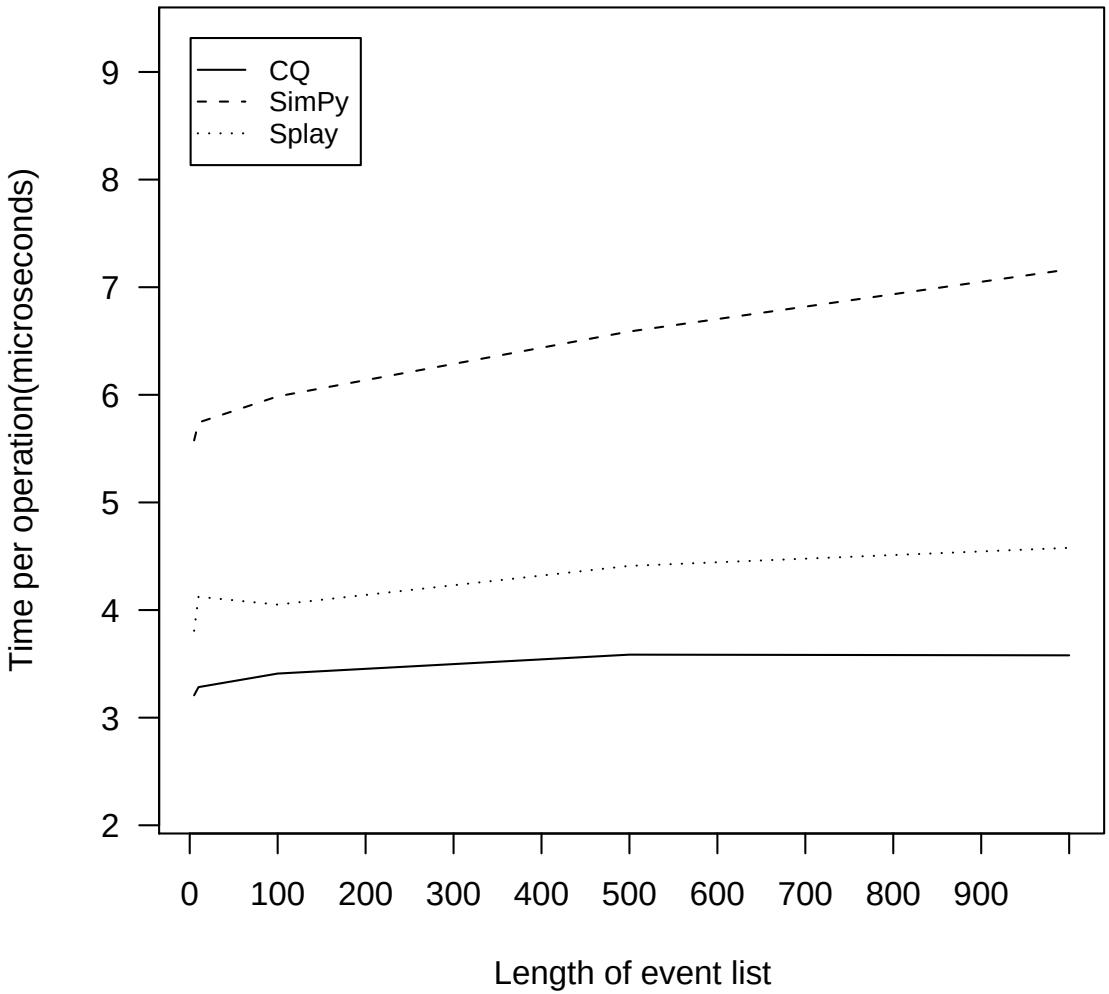
# Call Center Times Per Op, Higher Traffic



# Hold Model Times Per Op, Smaller COV



# Hold Model Times Per Op, Larger COV



# Scalability Issues

# Scalability Issues

Even though CQ and PQArr were about equal in performance, PQArr appears not to scale well to larger event sets:

# Scalability Issues

Even though CQ and PQArr were about equal in performance, PQArr appears not to scale well to larger event sets:

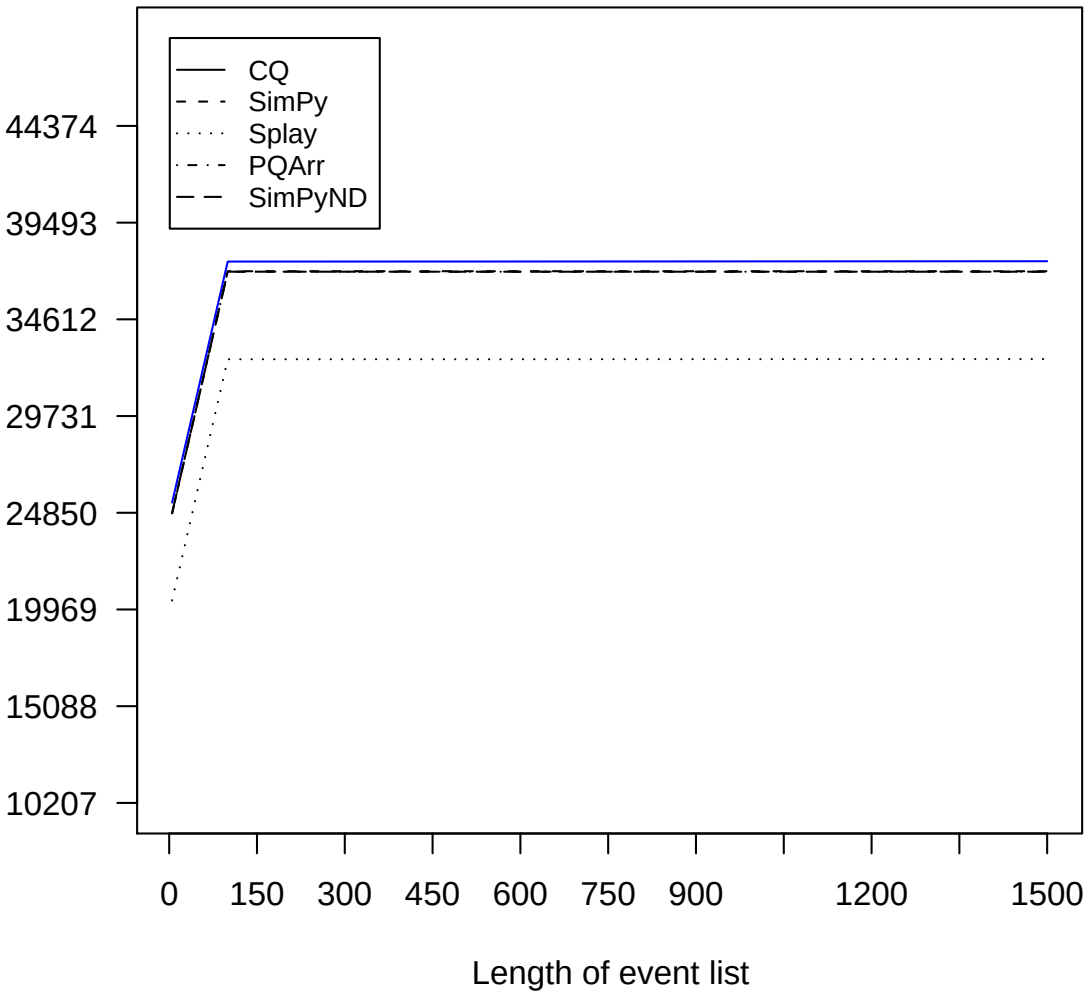
| struct | user time | sys. time | event op. time |
|---|---|---|---|
| PQArr | 79.47 | 4.50 | 57.87 |

# Scalability Issues

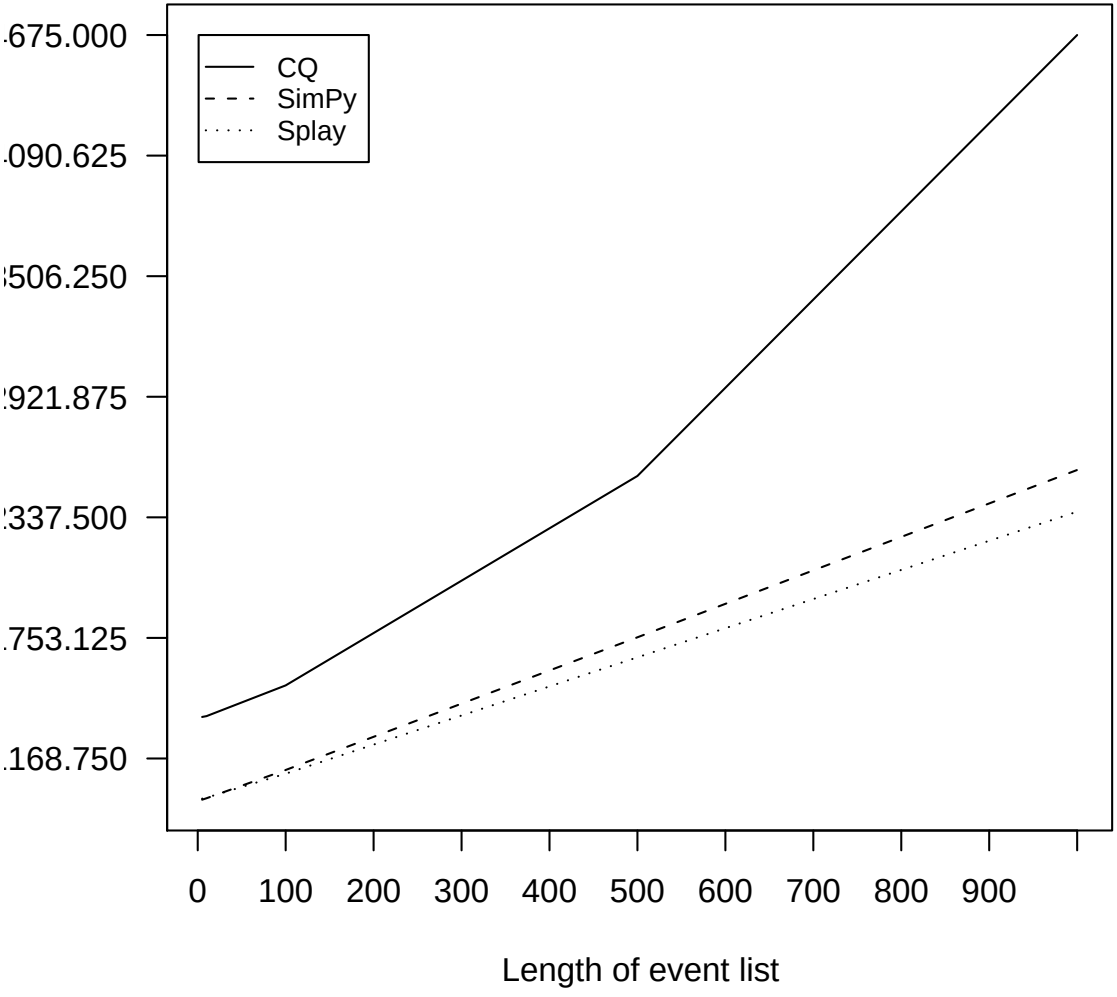
Even though CQ and PQArr were about equal in performance, PQArr appears not to scale well to larger event sets:

| struct | user time | sys. time | event op. time |
|---|---|---|---|
| PQArr | 79.47 | 4.50 | 57.87 |
| CQ | 33.24 | 3.95 | 12.69 |

# Number of Page Faults, Call Center (lower traffic)



# Number of Page Faults, Hold Model (medium COV)



# Discussion of VM Issues

# Discussion of VM Issues

- CQ paging performance poor in our experiments, run on 32-bit PCs running Linux kernel 2.6.20.

# Discussion of VM Issues

- CQ paging performance poor in our experiments, run on 32-bit PCs running Linux kernel 2.6.20.
- Preliminary experiments on a 64-bit PC, same kernel, suggest greater variability.

# Discussion of VM Issues

- CQ paging performance poor in our experiments, run on 32-bit PCs running Linux kernel 2.6.20.
- Preliminary experiments on a 64-bit PC, same kernel, suggest greater variability.
- $\therefore$ CQ may do poorly on some systems.

# Conclusions and Discussion

# Conclusions and Discussion

- Hybrid interpreted/C approach "best of both worlds"—transparent to apps programmer but with better performance

# Conclusions and Discussion

- Hybrid interpreted/C approach "best of both worlds"—transparent to apps programmer but with better performance
- Attention to non-algorithmic issues, e.g. paging, may be worthwhile.

# Conclusions and Discussion

- Hybrid interpreted/C approach "best of both worlds"—transparent to apps programmer but with better performance
- Attention to non-algorithmic issues, e.g. paging, may be worthwhile.
- What about JIT?

# Conclusions and Discussion

- Hybrid interpreted/C approach "best of both worlds"—transparent to apps programmer but with better performance
- Attention to non-algorithmic issues, e.g. paging, may be worthwhile.
- What about JIT? Tried Pyscho but with disappointing results.