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Simplifying Parallel Programming

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2010-6-25

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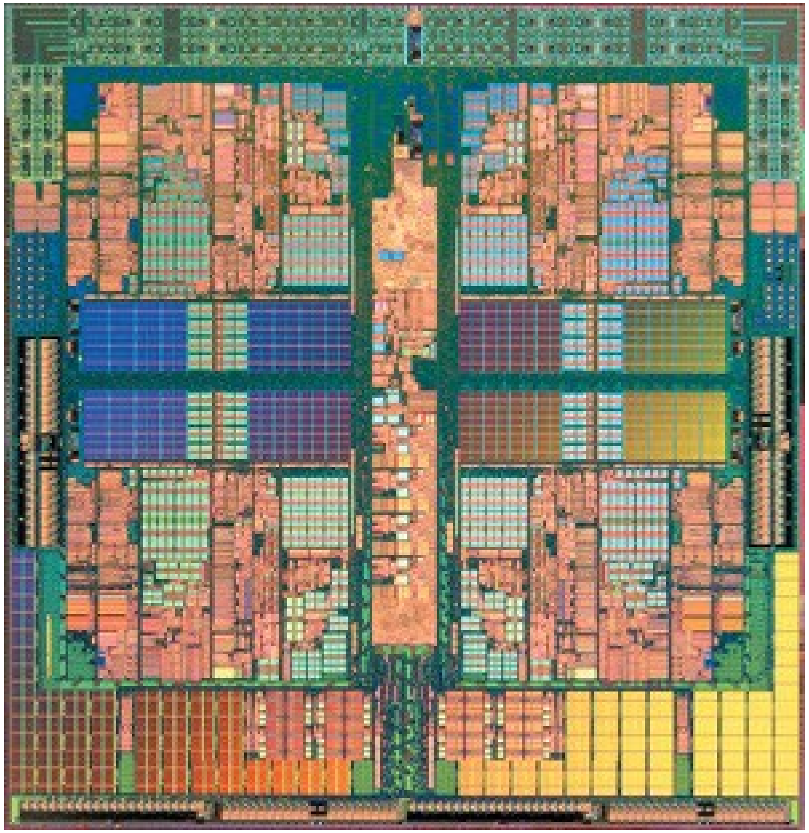
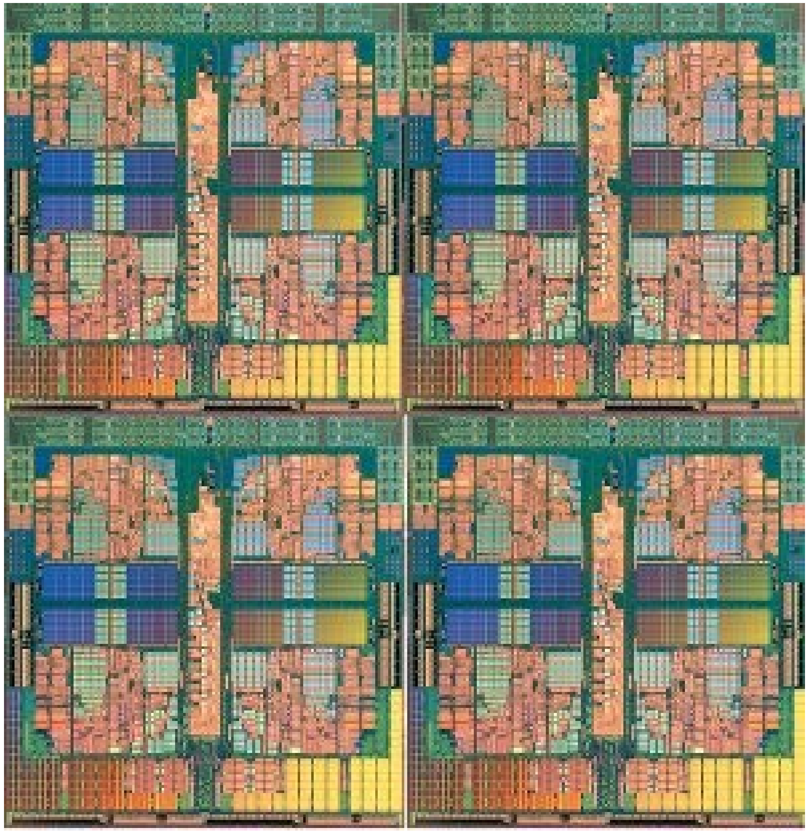
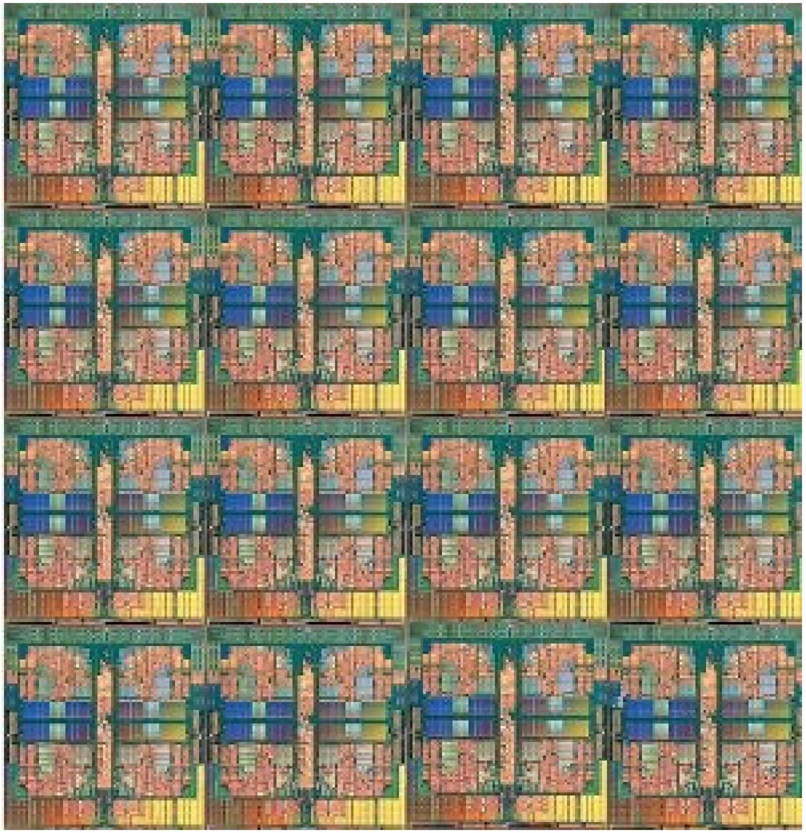
The Problem



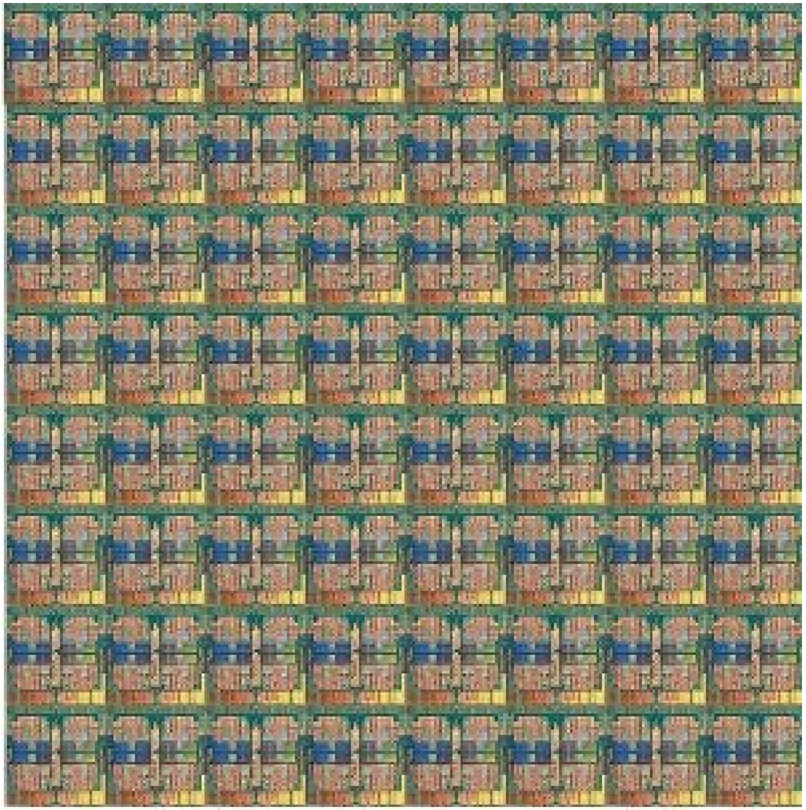
The Problem



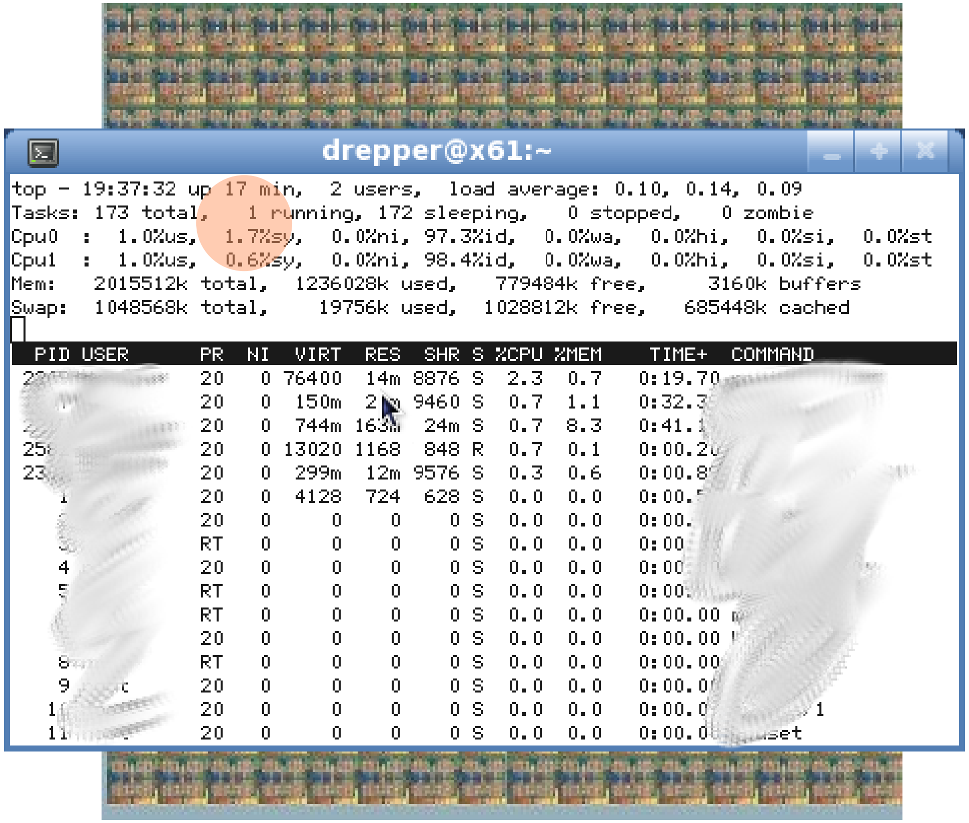
The Problem



The Problem



The Problem



```
top - 19:37:32 up 17 min,  2 users,  load average: 0.10, 0.14, 0.09
Tasks: 173 total,   1 running, 172 sleeping,   0 stopped,   0 zombie
Cpu0  :  1.0%us,  1.7%sy,  0.0%ni, 97.3%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Cpu1  :  1.0%us,  0.6%sy,  0.0%ni, 98.4%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:   2015512k total,  1236028k used,   779484k free,     3160k buffers
Swap:  1048568k total,    19756k used,  1028812k free,   685448k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 22             20   0 76400  14m 8876 S  2.3  0.7   0:19.70
                20   0  150m  2 m 9460 S  0.7  1.1   0:32.3
                20   0  744m 163m  24m S  0.7  8.3   0:41.1
 25             20   0 13020 1168  848 R  0.7  0.1   0:00.2
 23             20   0  299m  12m 9576 S  0.3  0.6   0:00.8
    1           20   0  4128  724  628 S  0.0  0.0   0:00.5
                20   0     0    0    0 S  0.0  0.0   0:00.
                RT   0     0    0    0 S  0.0  0.0   0:00
    4           20   0     0    0    0 S  0.0  0.0   0:00
    5           RT   0     0    0    0 S  0.0  0.0   0:00.
                RT   0     0    0    0 S  0.0  0.0   0:00.00
                20   0     0    0    0 S  0.0  0.0   0:00.00
    8           RT   0     0    0    0 S  0.0  0.0   0:00.00
    9           20   0     0    0    0 S  0.0  0.0   0:00.0
   1            20   0     0    0    0 S  0.0  0.0   0:00.0        1
   11           20   0     0    0    0 S  0.0  0.0   0:00.0      set
```

The Reason

$$E = C \times V^2 \times f$$

More Correctly

$$E = C \times V(f)^2 \times f$$

Use of Transistors

- Increasing frequency is out
- Two uses
  - More complex architecture
    - Handle existing instructions faster
    - More specialized instructions
  - Horizontal growth
    - More execution cores; or
    - Only more execution contexts

Requires Parallelism!

Cost of Too Little Parallelism

- Idealized Amdahl's Law

$$S = \frac{1}{(1-\boldsymbol{P}) + \dfrac{\boldsymbol{P}}{N}}$$

- Problems
  - ***P*** too small
  - *N* is steadily growing
- Formula is unrealistic though…

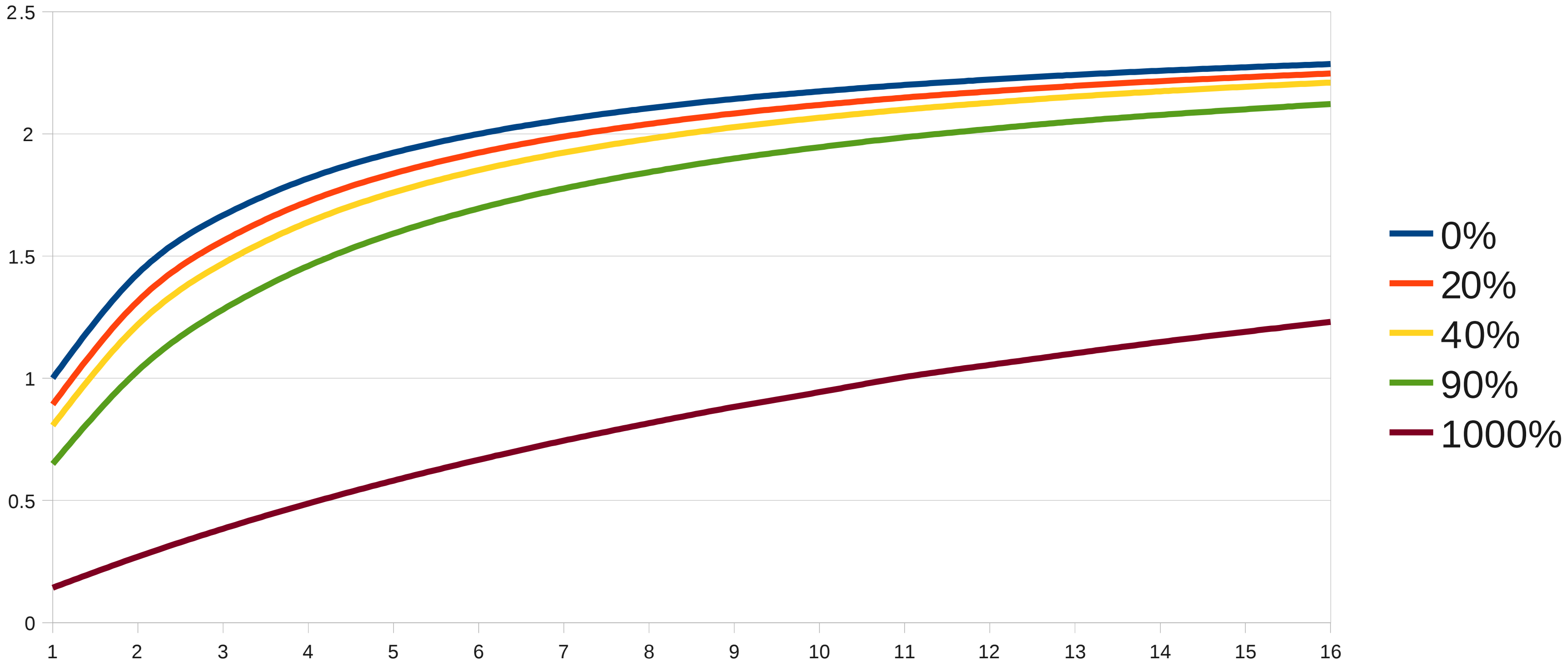
A More Realistic Formula

- Extended Amdahl's Law with Overhead

$$S = \frac{1}{(1-P)\,(1+O_S) + \frac{P}{N}\,(1+O_P)}$$

- Parallelization is not free
  - Most of the time not even for serial code
- The results are not *that* bad…

Even with Overhead P=0.6



- Even with 40% overhead not that much slower
- Speed-up from two threads on
  - Eleven threads for 10x slowdown

Programming Goals

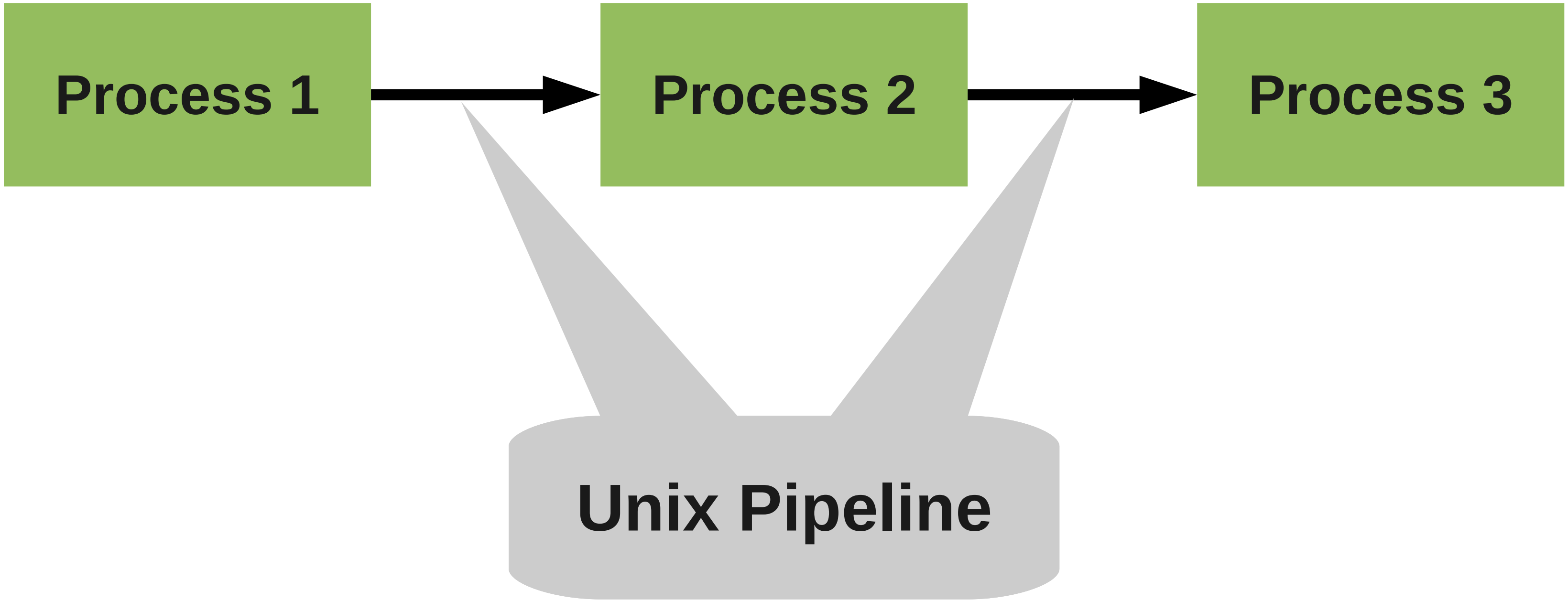
$$S = \frac{1}{(1-P)\,(1+O_S) + \frac{P}{N}\,(1+O_P)}$$

- Two goals: 1. ease parallel programming to increase P

  2. reduce O_S and O_P

Getting Parallelism

- Multi-process Pipeline



Problems with Pipelines

- Marshalling needed for transmission
- Protocol standardization required
- Limited buffer sizes
  - Lots of scheduling needed
- Program need to be designed for pipeline
  - Extending an existing program not easy
  - Major code restructuring needed

Problems with Pipelines

- Marshalling needed for transmission
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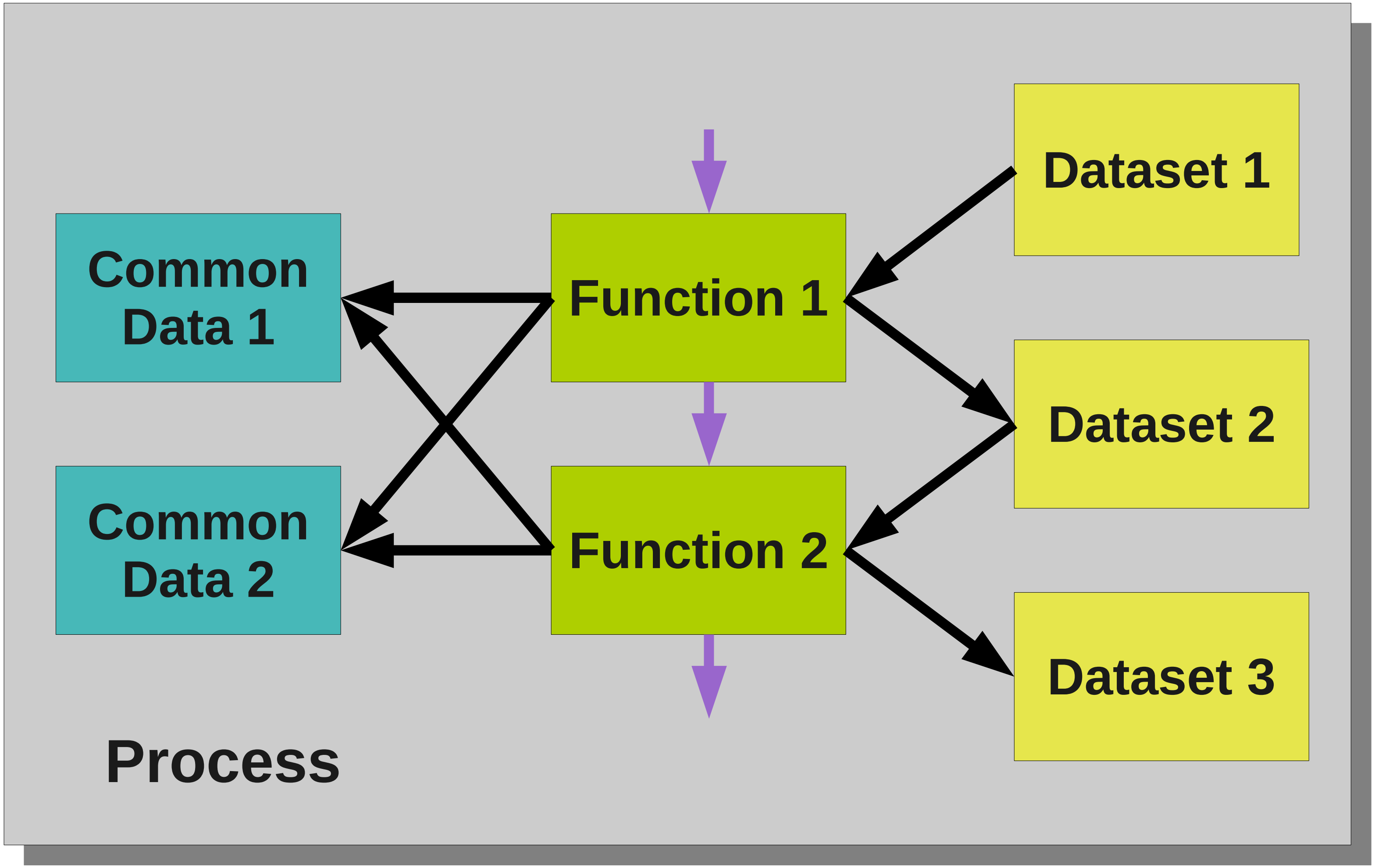
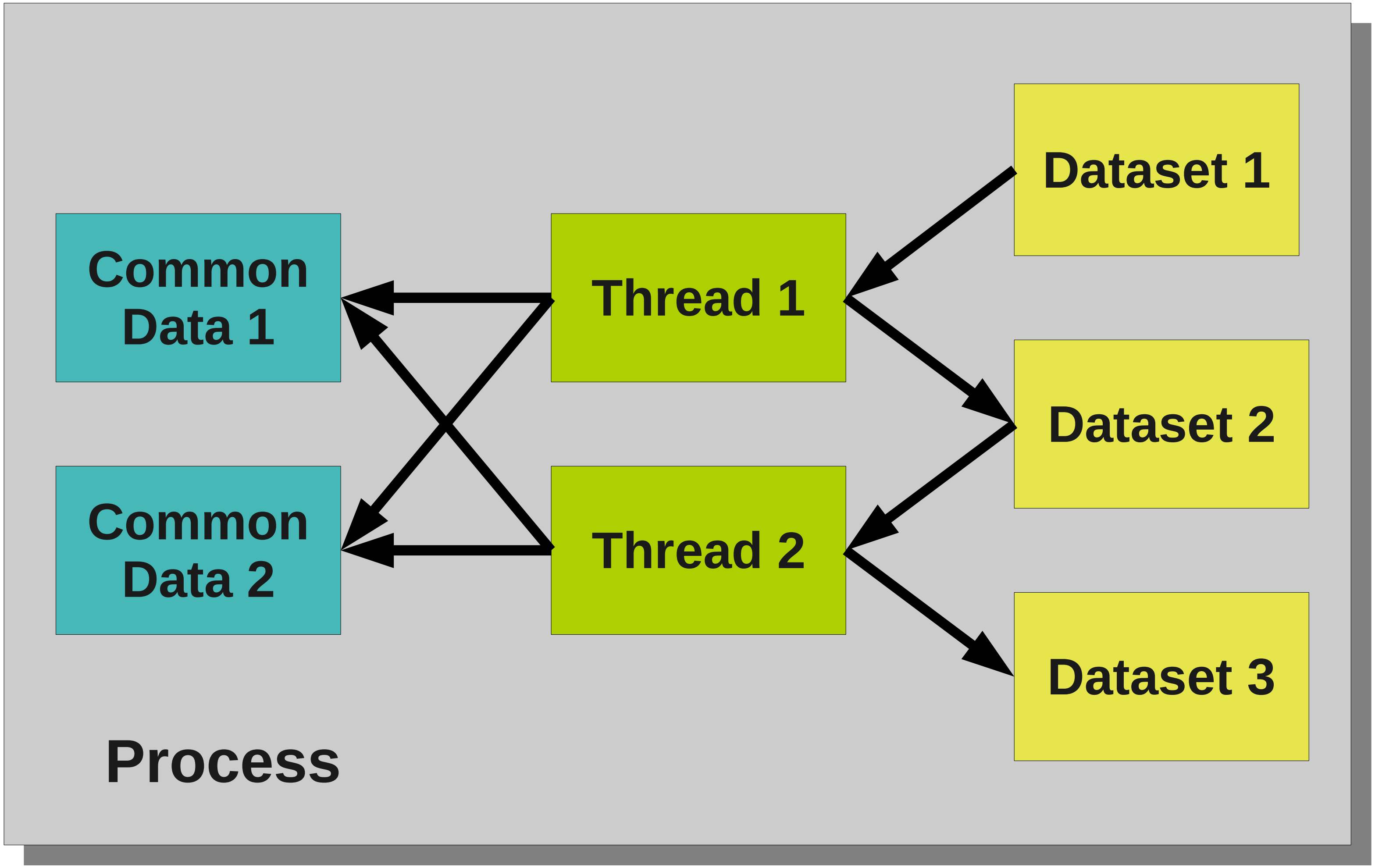
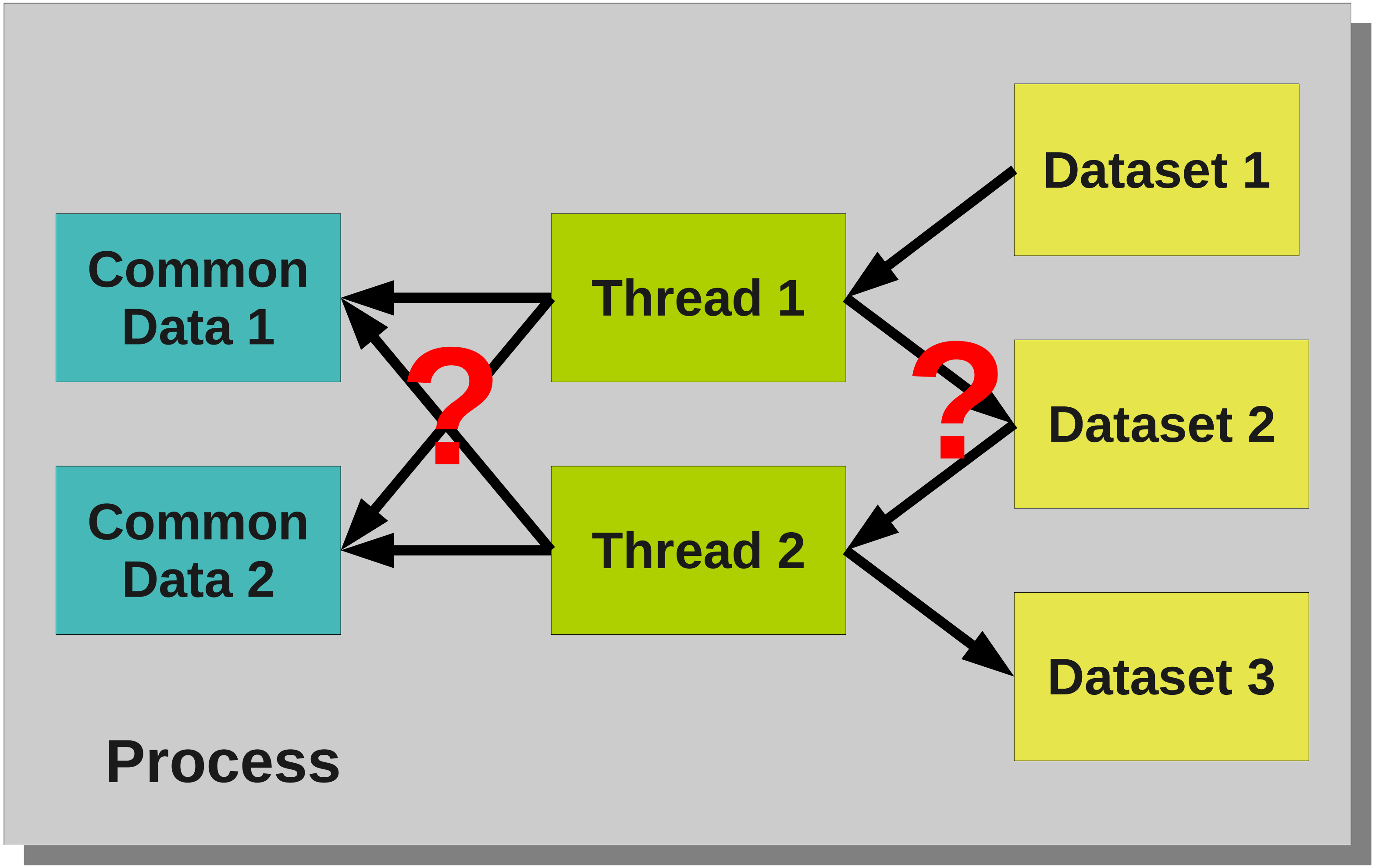
Simple Program Structure



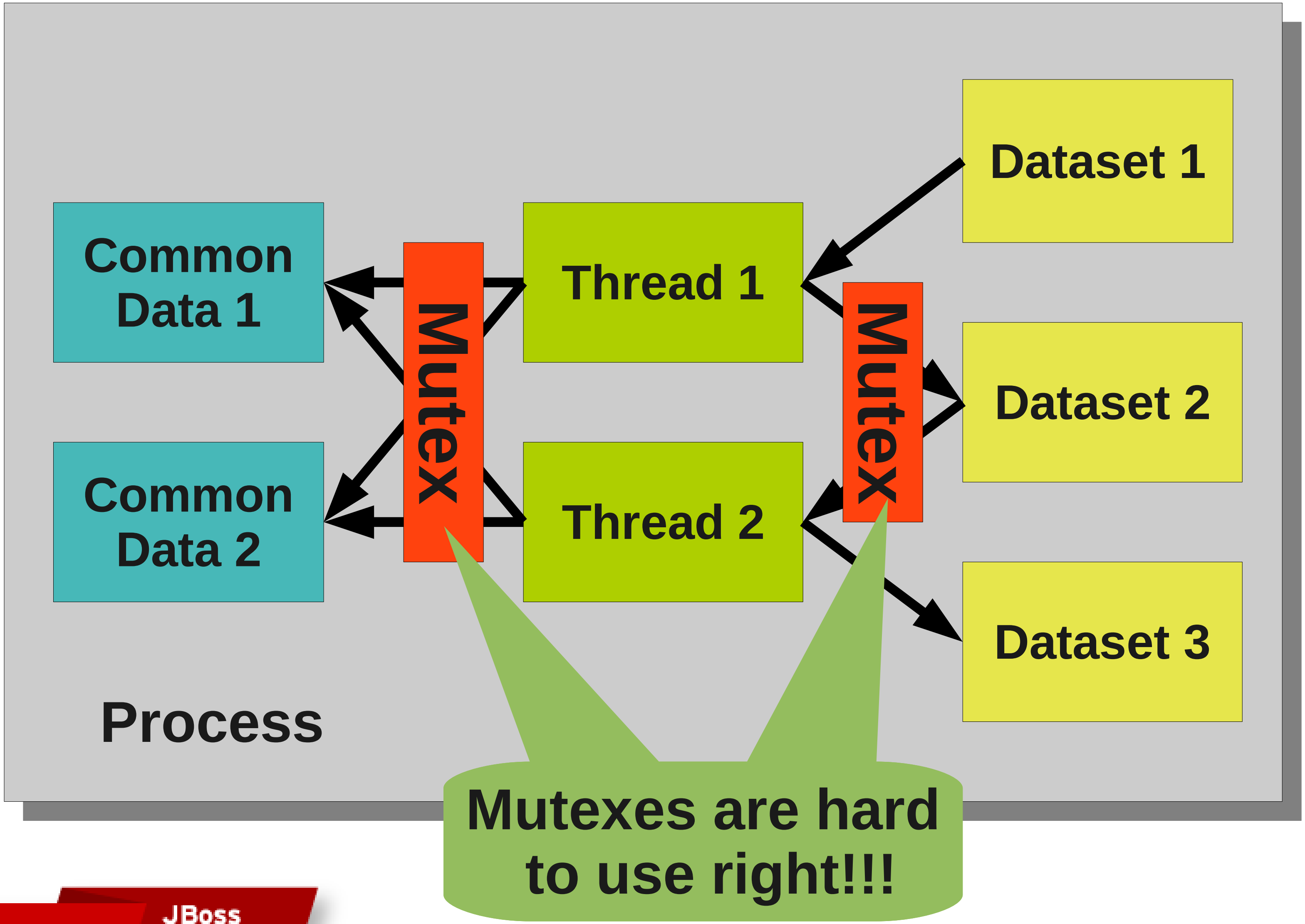
“Easy” Fix


Dataset 1
Common Data 1
Thread 1
Dataset 2
Common Data 2
Thread 2
Dataset 3
Process

“Easy” Fix


Common Data 1
Common Data 2
Thread 1
Thread 2
Dataset 1
Dataset 2
Dataset 3
?
?
Process

It seems easy…



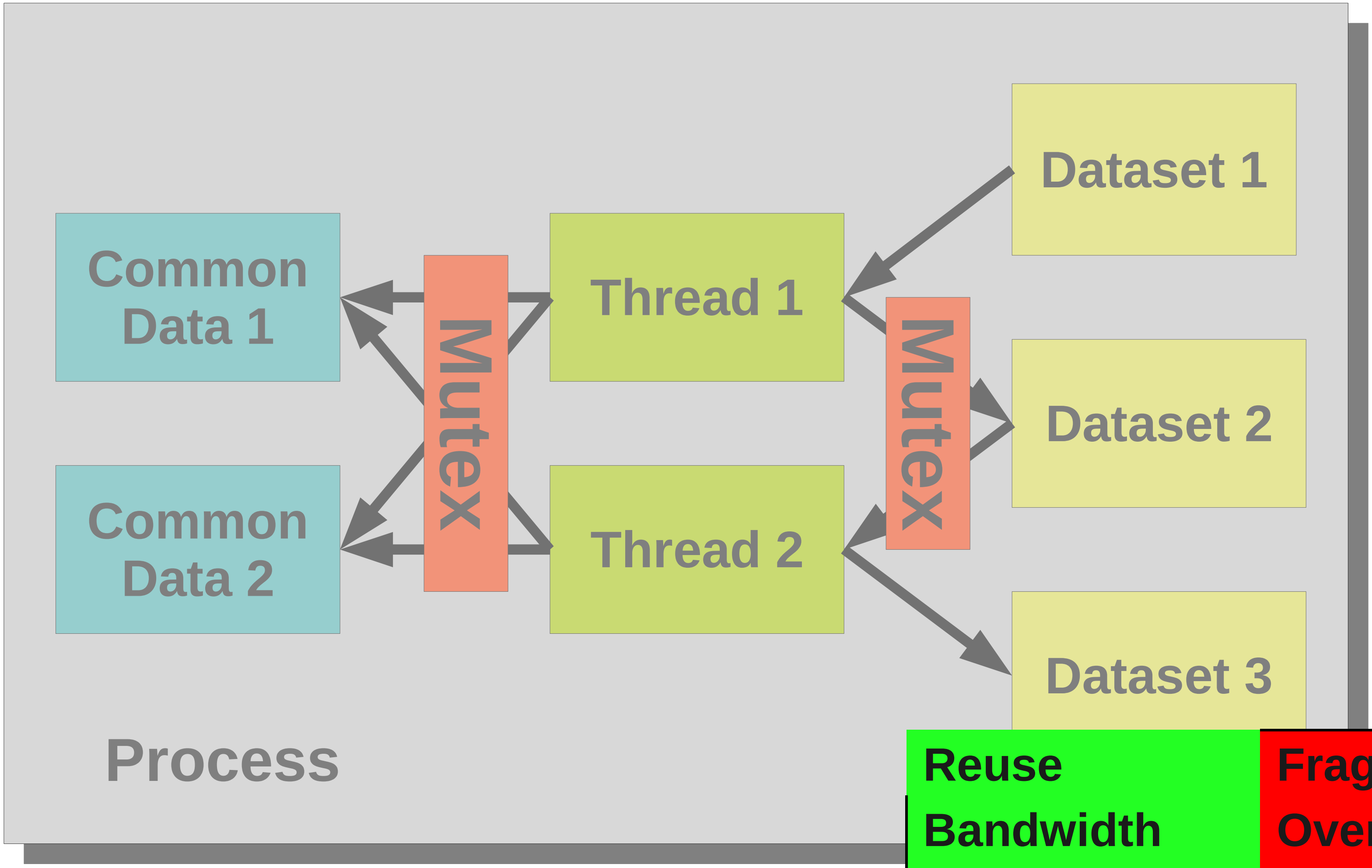
Mutexes are hard to use right!!!

Explicit Multi-Threading

- Ill-conceived solution
  - Yes
    - Existing code can be reused, easier to set up
    - High-bandwidth inter-thread communication
    - On some OSes context switching faster
  - But:
    - Fragile programming model (one thread dies, the process dies)
    - Memory handling mistakes have global effects
    - Unix model initially not designed for multiple threads

Hard to write correct code! High Cost!

Measures



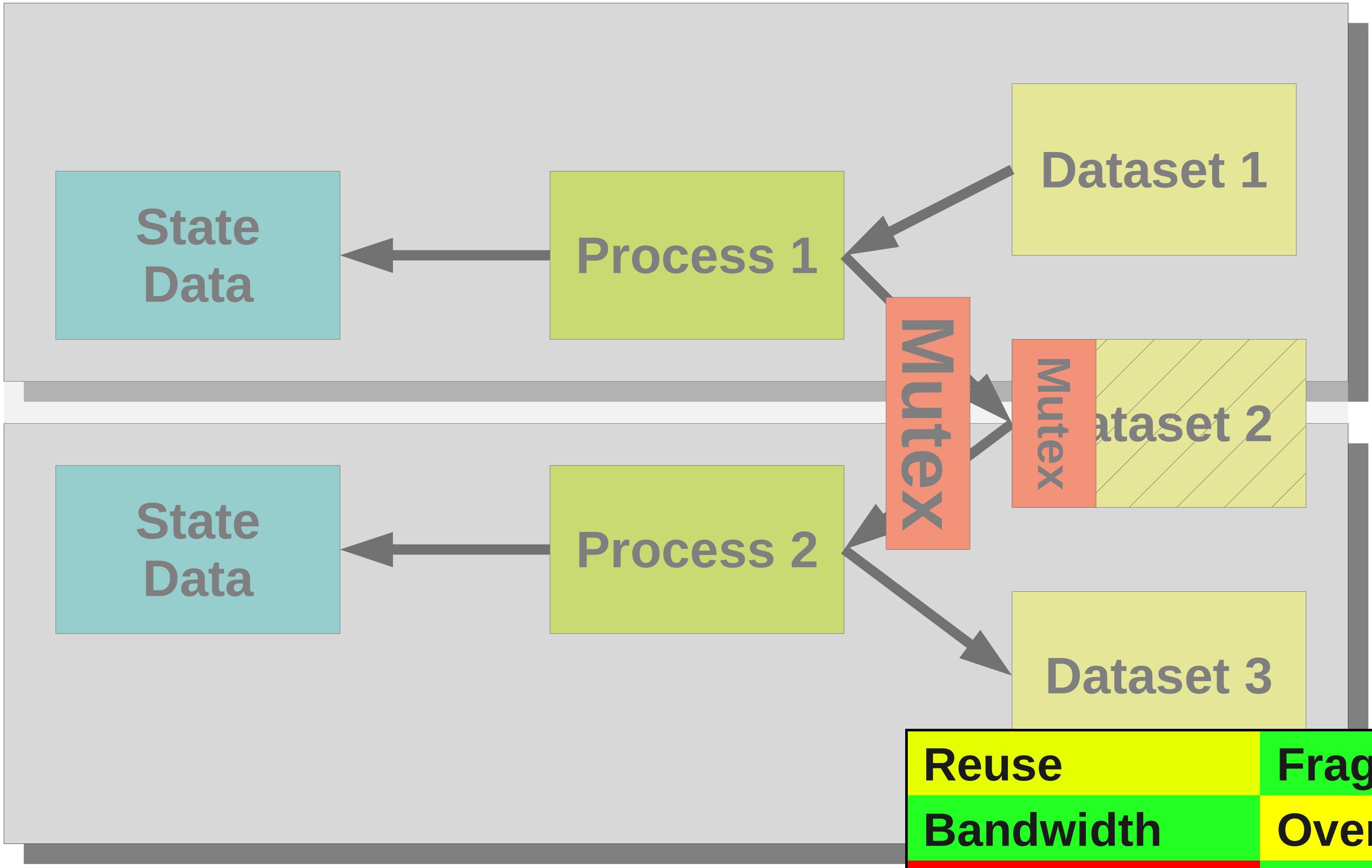
Reuse	Fragile
Bandwidth	Overwrites
Context Cost	Unix model
Ease Program	Error Prone

Alternative 1: fork and Shared Memory

- All in POSIX:

```
int fd = shm_open(name, O_RDWR|O_CREAT);
ftruncate(fd, size);
p = mmap(NULL, size, PROT_READ|PROT_WRITE,
         MAP_SHARED, fd, 0);
if (fork() == 0)
   ...
```

`fork` and Shared Memory



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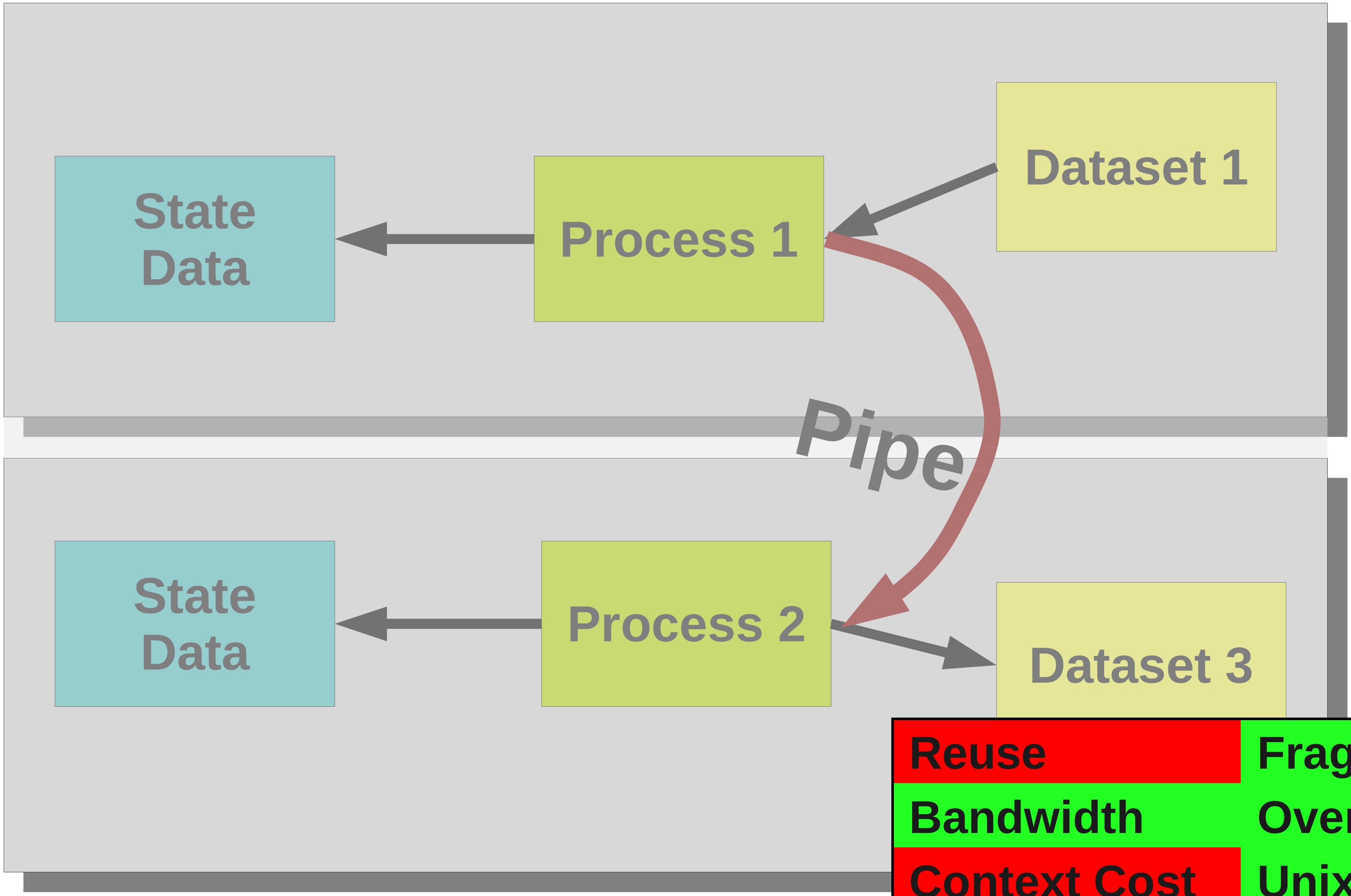
Alternative 2: `fork` and Linux Pipes

- Linux extensions, not POSIX (yet ☺)
- Can be zero-copy
- Use if just transferring data without inspection
- splice: transfer from file descriptor to pipe
- tee: transfer between pipes and keep data usable
- vmsplice: transfer from memory to pipe

fork and Linux Pipes



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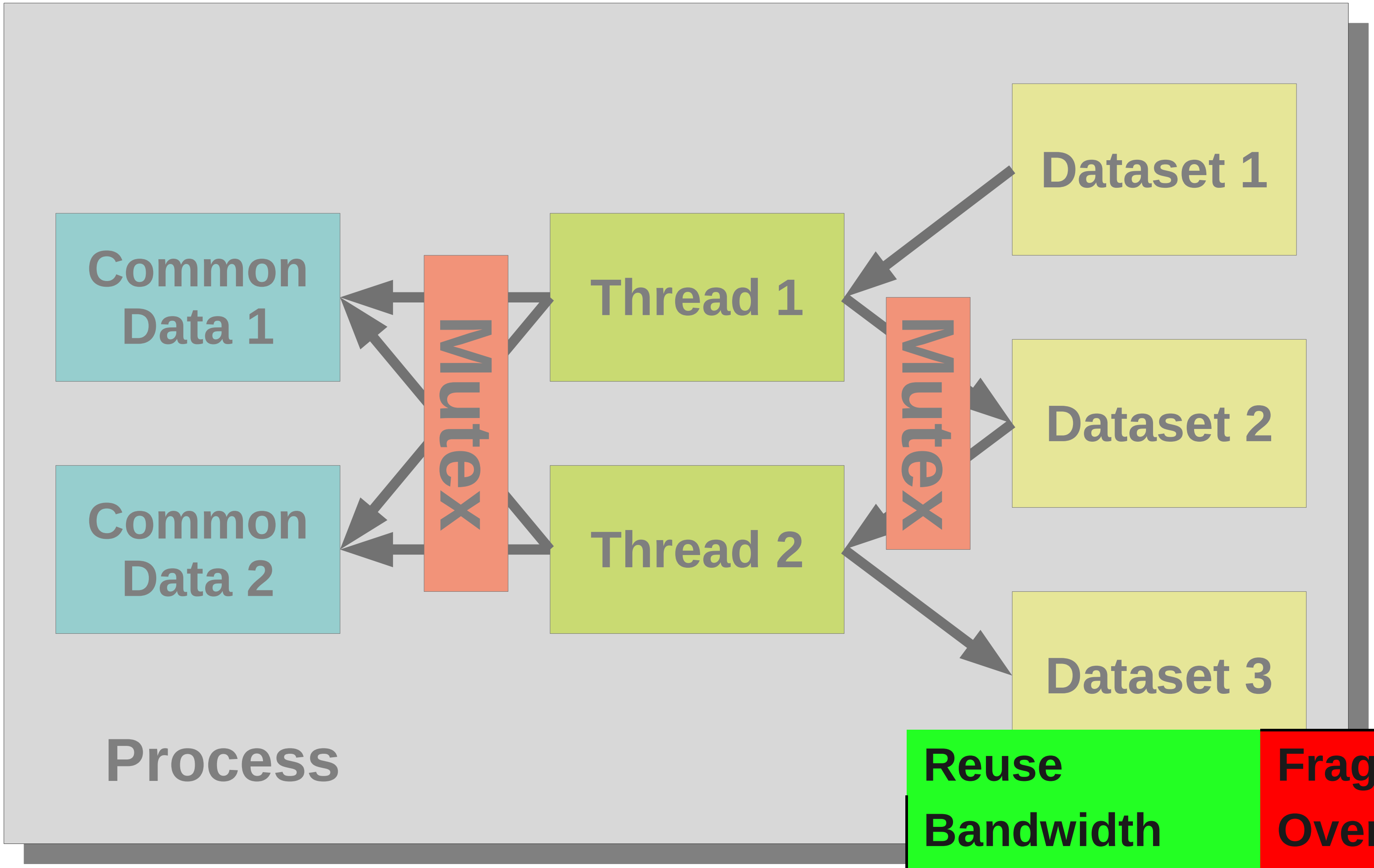
Alternative 3: Thread Local Storage

- Use thread-local storage
  - Very much simplifies use of static variables
  - No more false sharing of cache lines

```
__thread struct foo var;
```

Thread Local Storage



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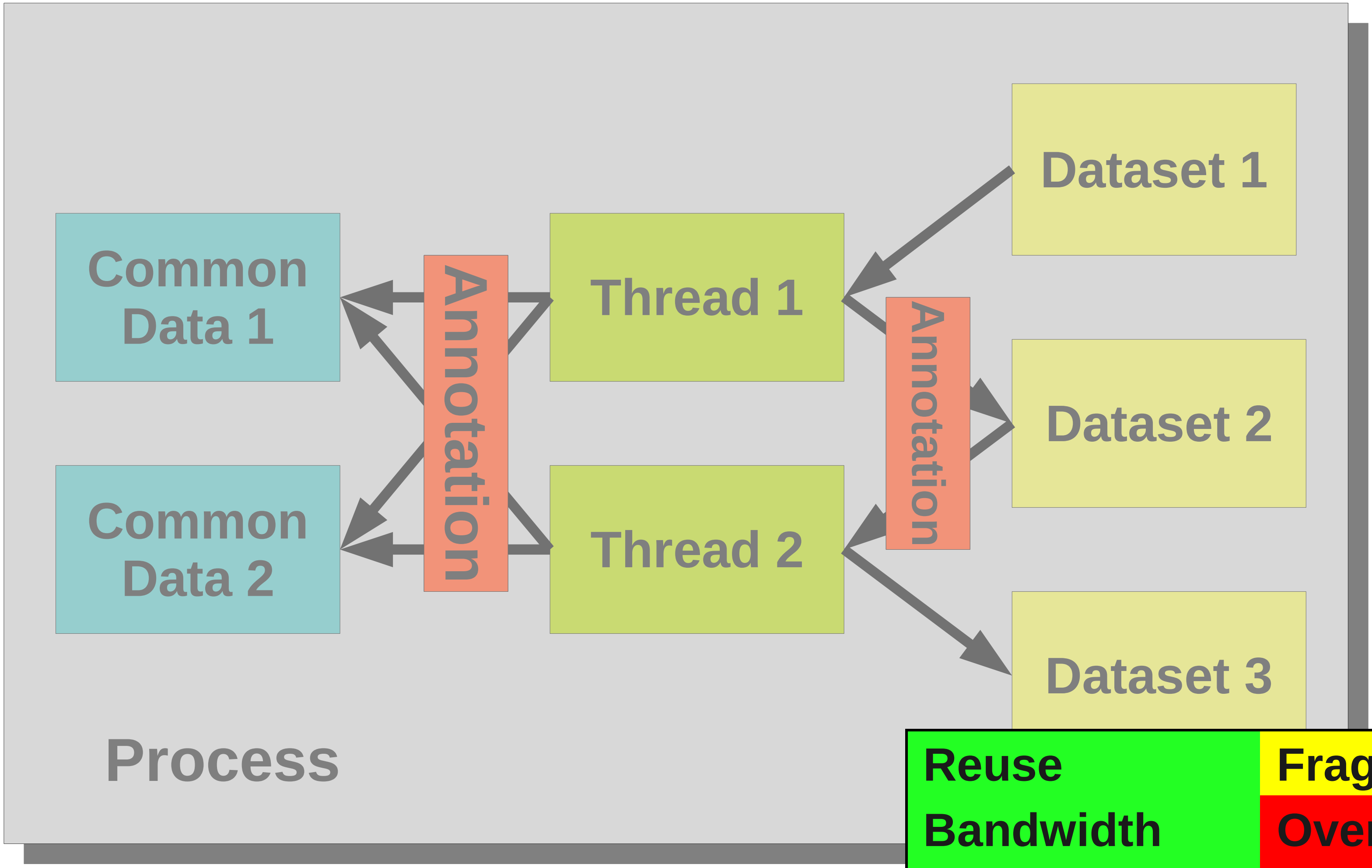
Alternative 4: OpenMP

- Language extension to C, C++, Fortran languages
- Implements many thread functions with very simple interface for
  - Thread creation (controlled)
  - Exclusion
  - Thread-local Data

OpenMP



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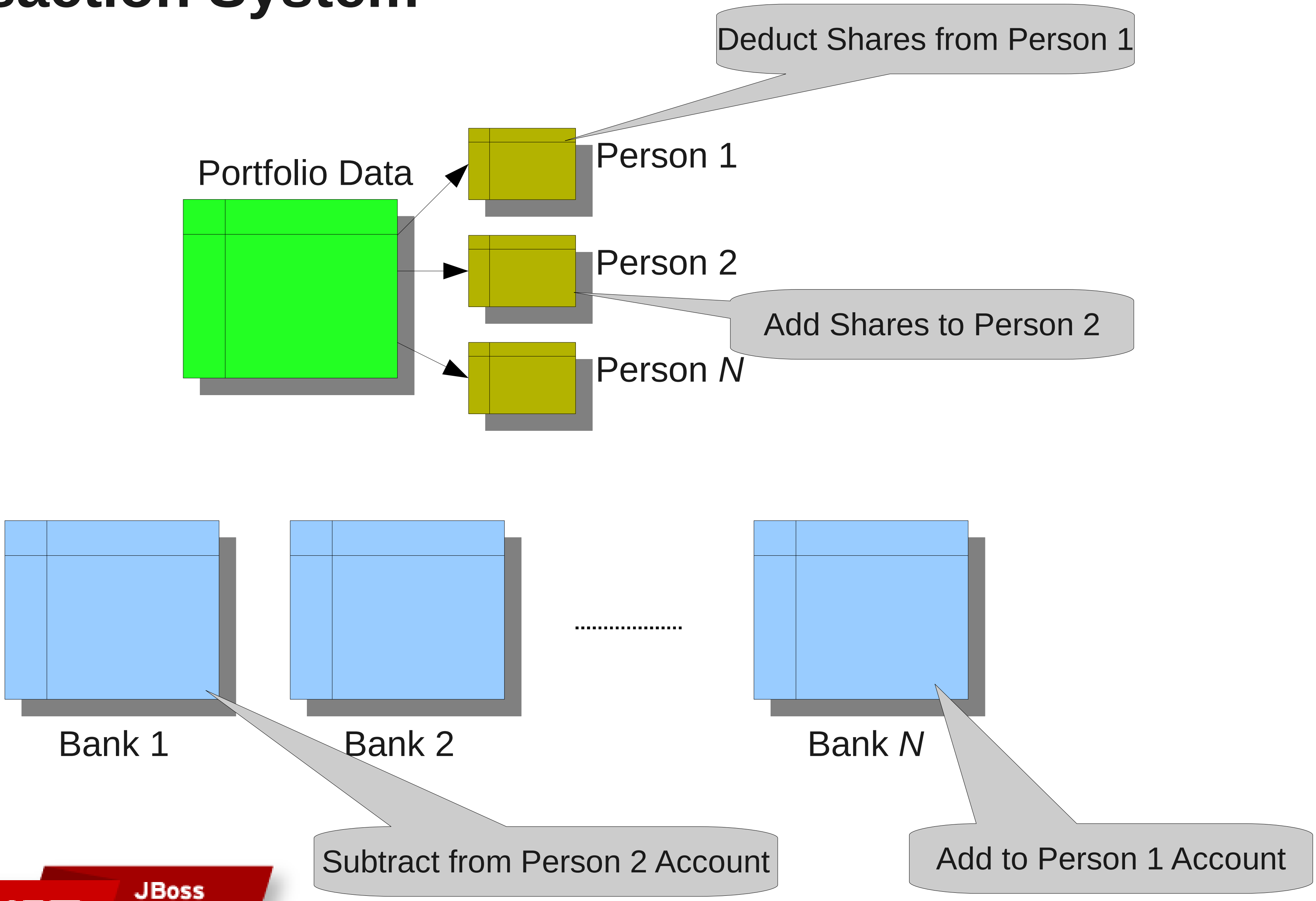
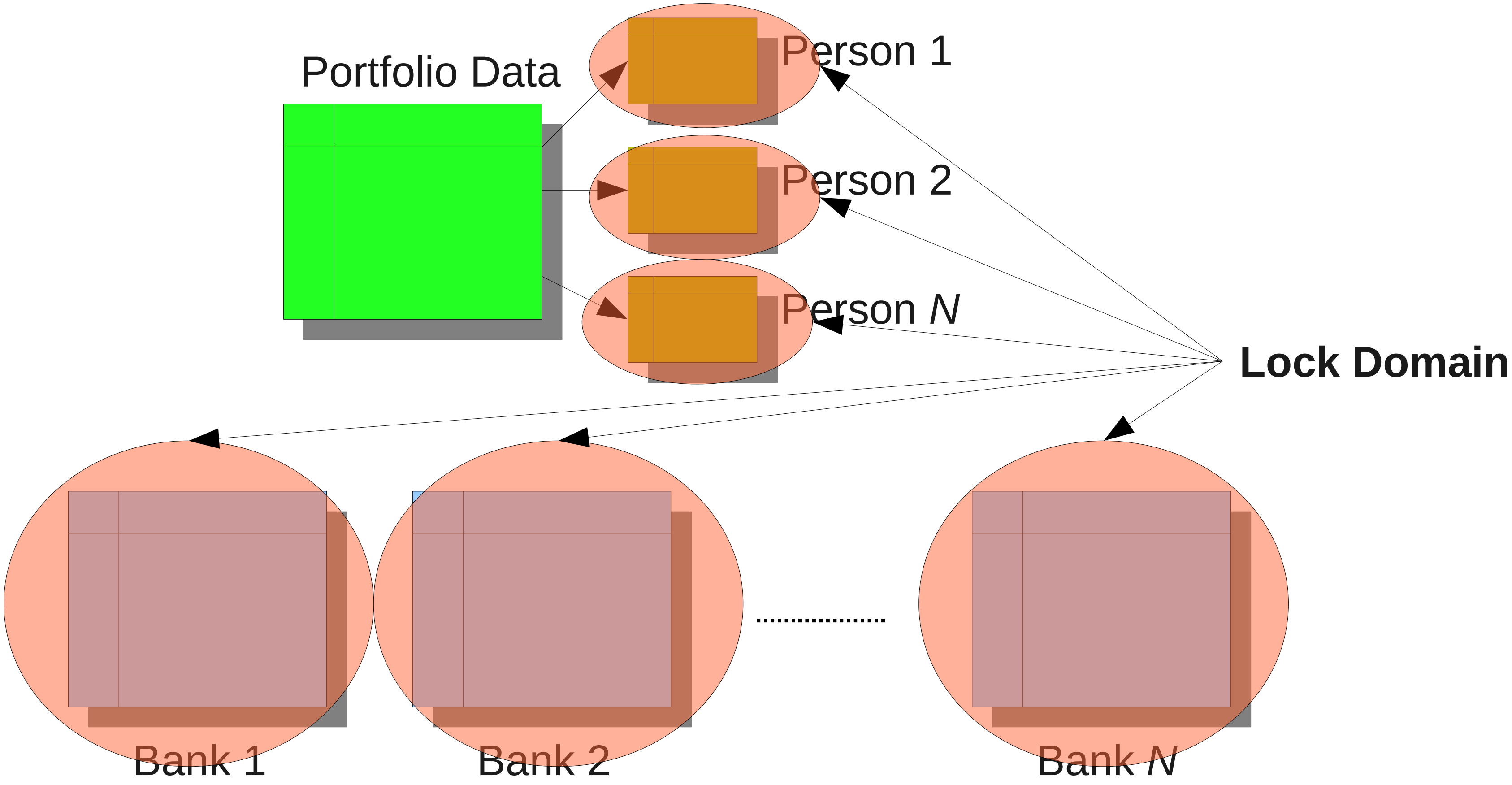
Alternative 5: Transactional Memory

- Extensions to C and C++ languages
- Can help to avoid using mutexes
  - Just source code annotations
  - No more deadlocks!!
  - Fine-grained locking without the problems
- Slow as pure software solutions
  - Hardware support on the horizon

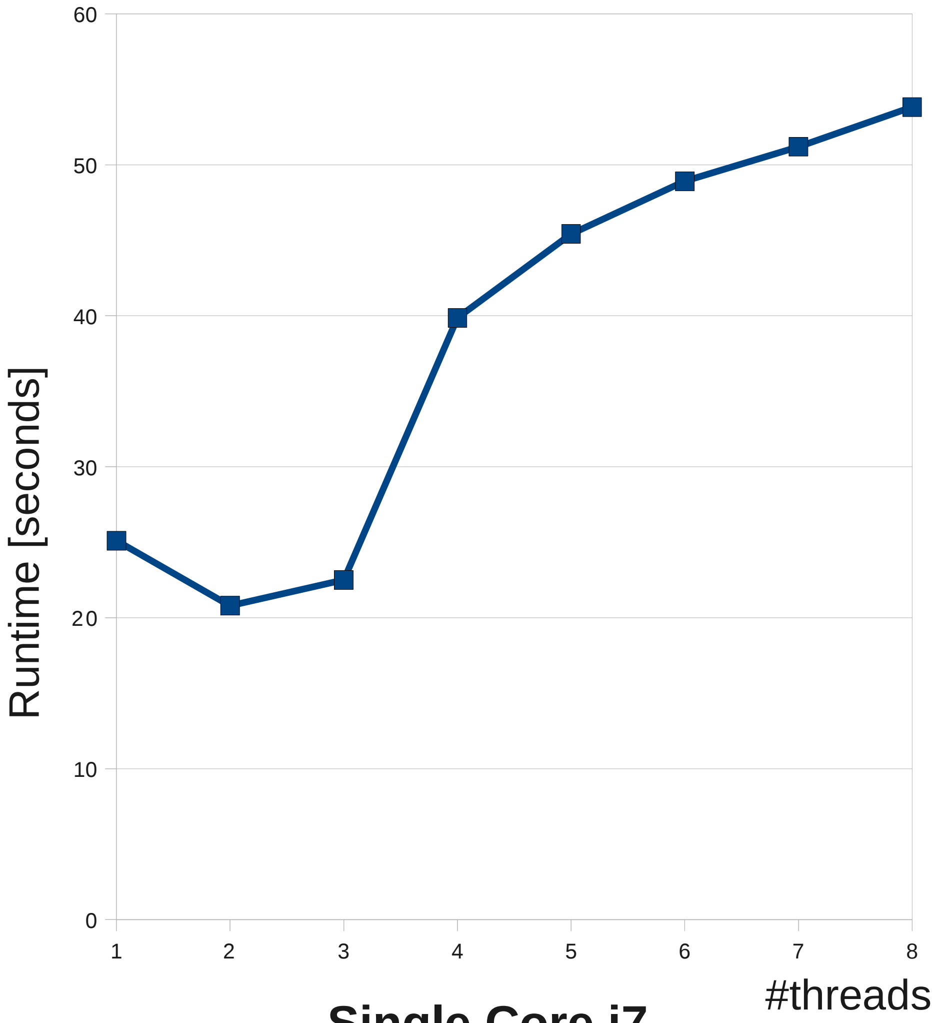
Transaction System



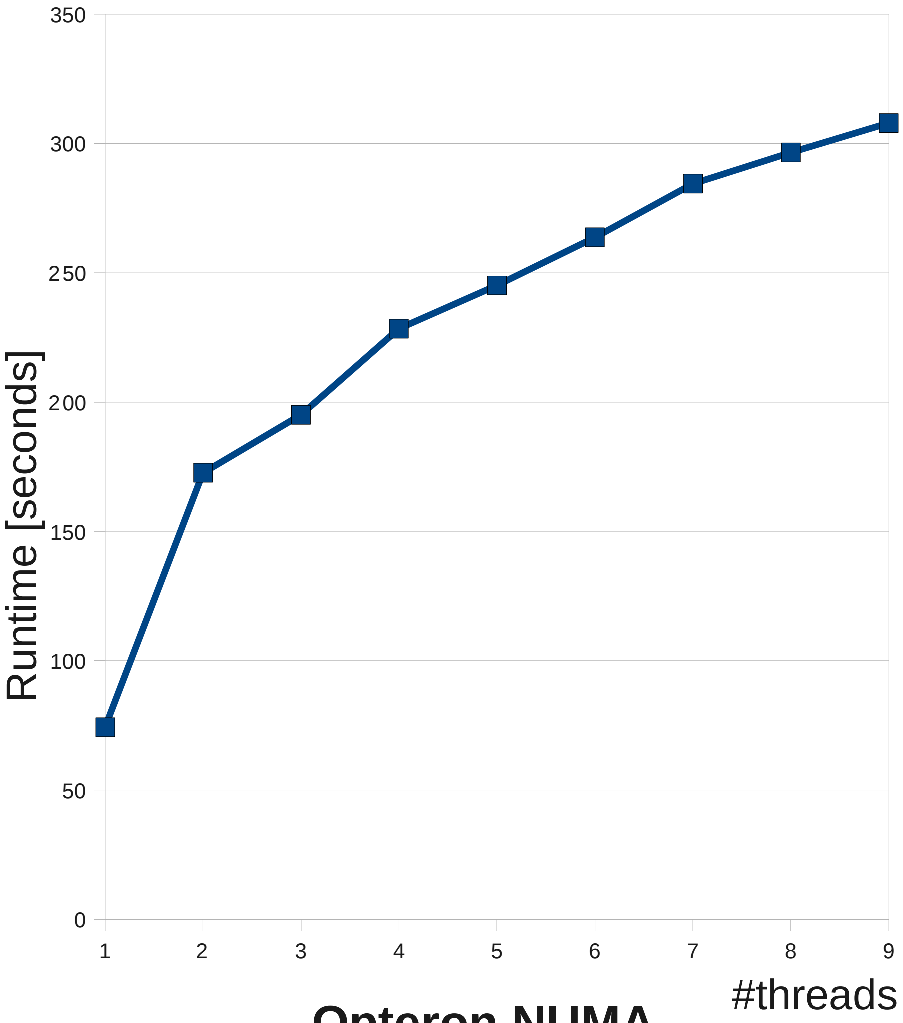
Trying to Parallelize



Not What We Want

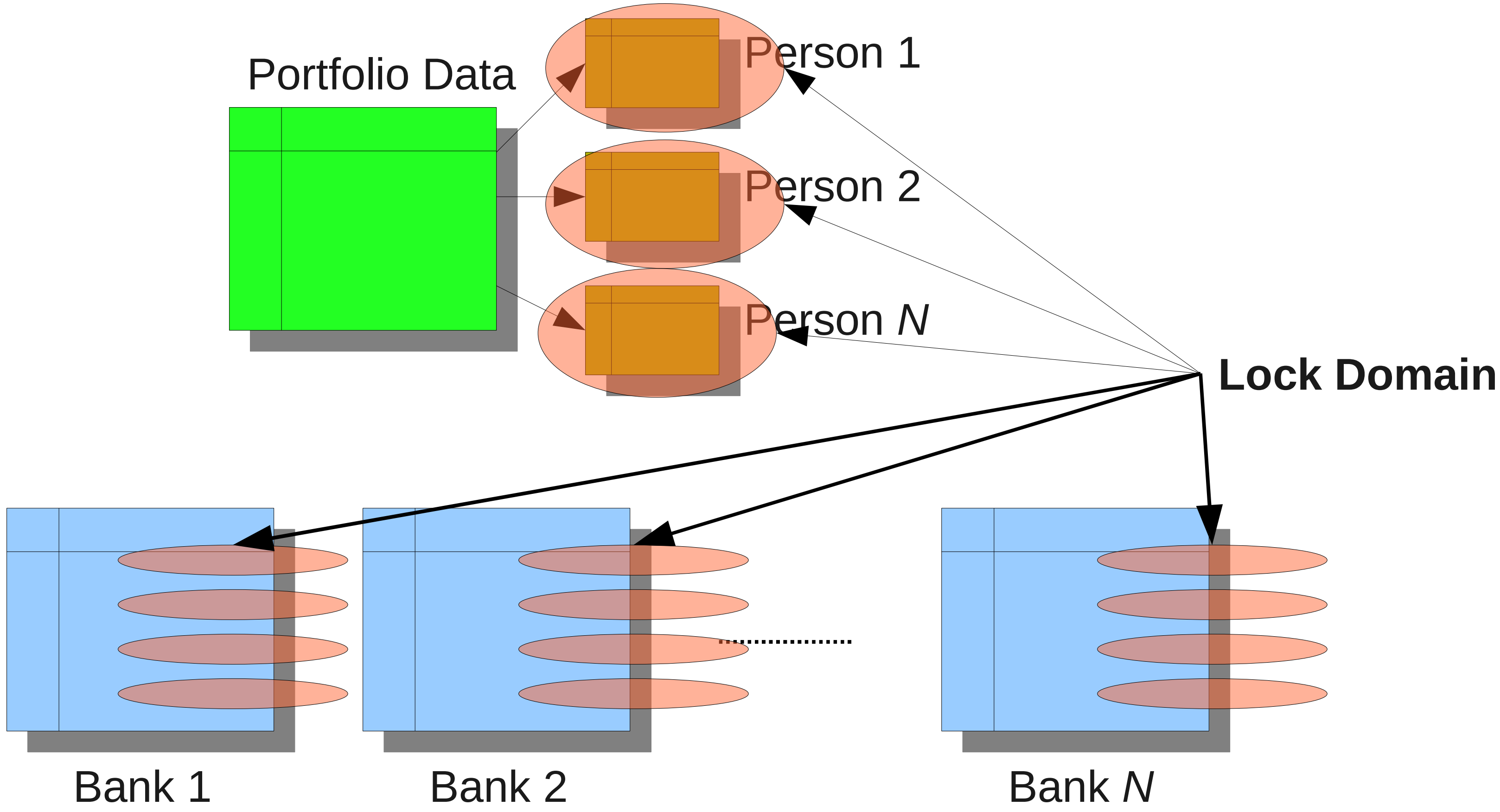


Single Core i7

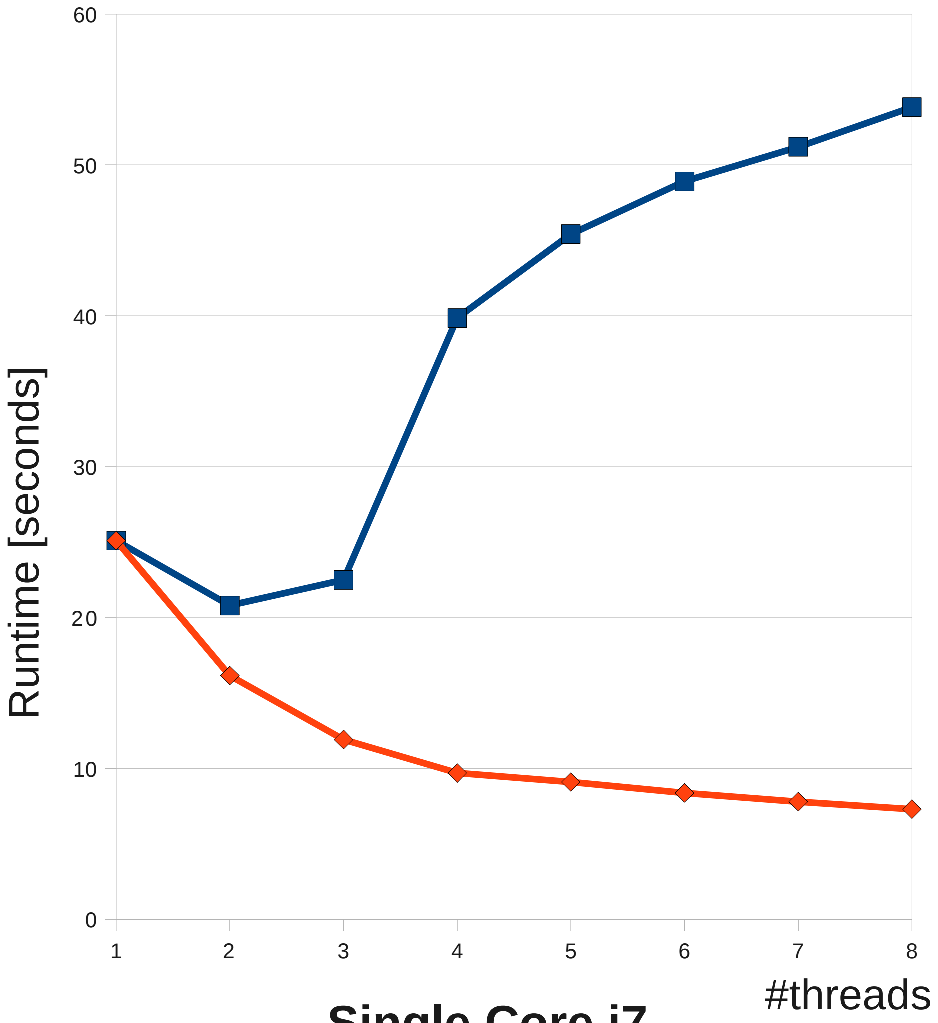


Opteron NUMA

Trying to Parallelize



Somewhat Better But…



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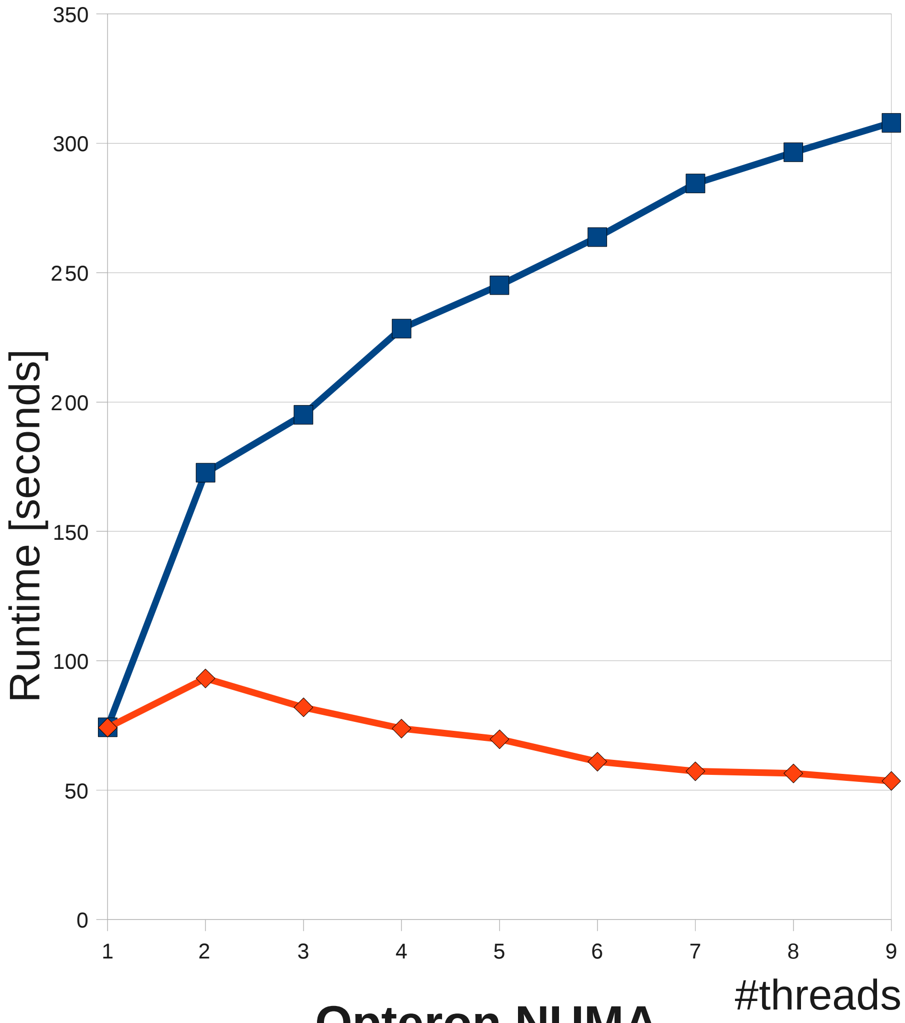
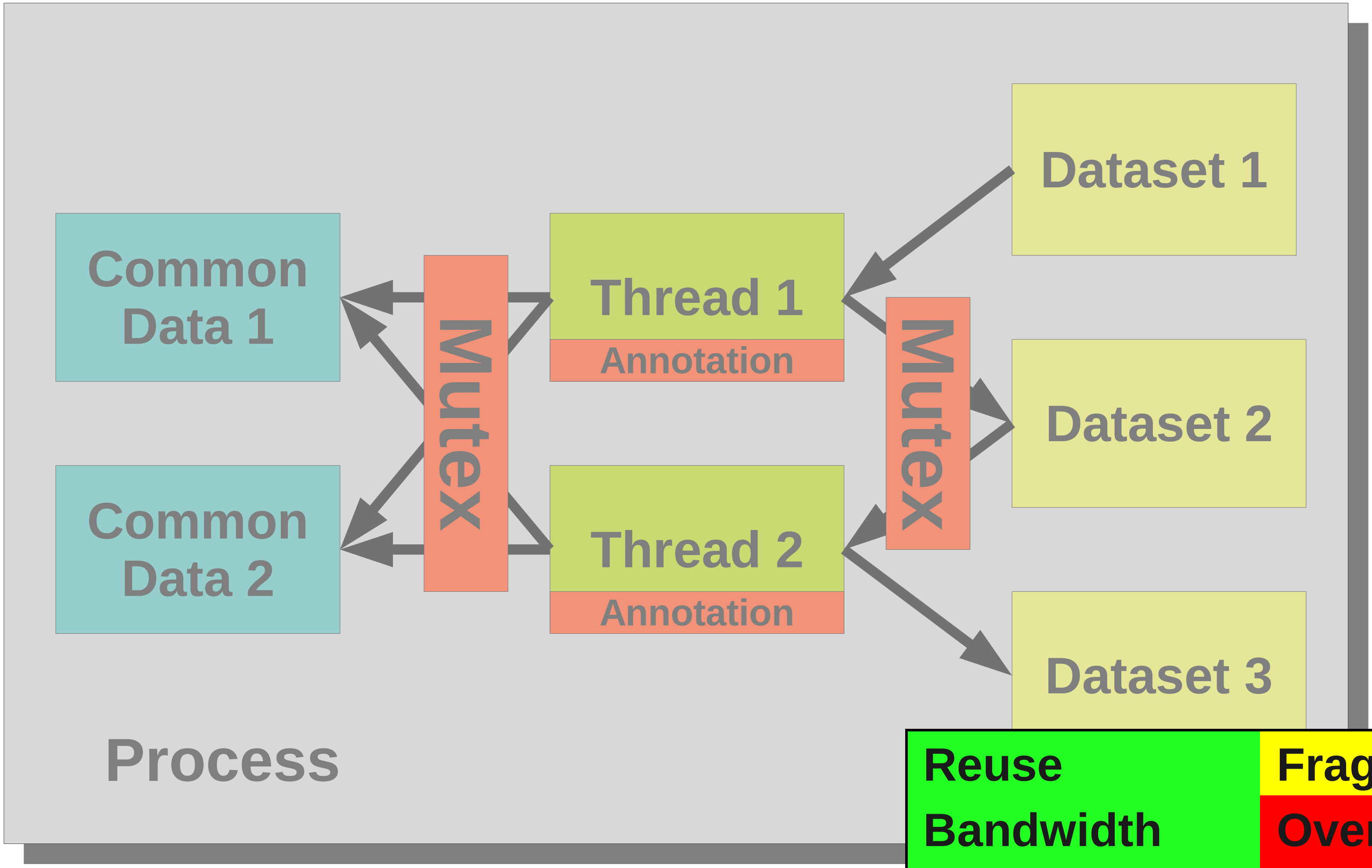


Opteron NUMA

Transactional Memory



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Conclusion

- Abilities to exploit hardware are there
  - Explicit threading only for experts
- But there is a lot of help
  - Use processes, not threads; or
  - If threads are used combine
    - Thread-local storage
    - Implicit thread creation
      - OpenMP
      - Futures
    - Transactional memory

Questions?

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