Parallel Computing

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Types of “Parallel” Computing

- Nomenclature
  - Parallel vs. concurrent
  - Bit-level vs. data level
- Multi-threaded
- Multi-process
- Distributed
- Grid
- SIMD
- GPU/GPGPU
- MIC

SIMD = Single Instruction Multiple Data

- Special registers on CPU where multiple numbers can be packed and operated on simultaneously
- Also known as "vectorization"
  - *gcc: "…vectorization is enabled by the flag -ftree-vectorize and by default at -O3"*
- CPU vendors have their own implementations and evolutions
  (e.g. Intel has …)
  - MMX (1997, Pentium 5) 64bit
  - SSE (1999) – SSE4(2006) 128 bit
  - AVX (2008) 256 bit
  - MIC/VPU 512 bit

SIMD = Single Instruction Multiple Data

- Special registers on CPU where multiple numbers

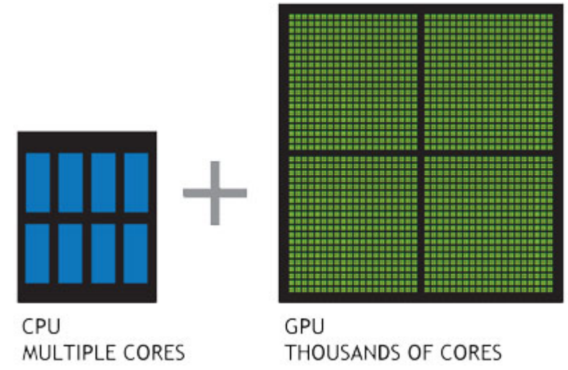
```
// Multiply a 5x1 matrix by its transpose
inline DMatrix5x5 MultiplyTranspose(const DMatrix5x1 &m1){
  ALIGNED_16_BLOCK_WITH_PTR(__m128d, 5, p)
  __m128d &b1=p[0];
  __m128d &b2=p[1];
  __m128d &b3=p[2];
  __m128d &b4=p[3];
  __m128d &b5=p[4];
  b1=_mm_set1_pd(m1(0));
  b2=_mm_set1_pd(m1(1));
  b3=_mm_set1_pd(m1(2));
  b4=_mm_set1_pd(m1(3));
  b5=_mm_set1_pd(m1(4));
  return DMatrix5x5(_mm_mul_pd(m1.GetV(0),b1),_mm_mul_pd(m1.GetV(0),b2),
            _mm_mul_pd(m1.GetV(0),b3),_mm_mul_pd(m1.GetV(0),b4),
            _mm_mul_pd(m1.GetV(0),b5),
            _mm_mul_pd(m1.GetV(1),b1),_mm_mul_pd(m1.GetV(1),b2),
            _mm_mul_pd(m1.GetV(1),b3),_mm_mul_pd(m1.GetV(1),b4),
            _mm_mul_pd(m1.GetV(1),b5),
            _mm_mul_pd(m1.GetV(2),b1),_mm_mul_pd(m1.GetV(2),b2),
            _mm_mul_pd(m1.GetV(2),b3),_mm_mul_pd(m1.GetV(2),b4),
            _mm_mul_pd(m1.GetV(2),b5));
}
```

  - MIC/VPU 512 bit

GPU = Graphics Processing Unit

- Driven by gaming industry where high frame rates of complex environments was required
- Many cores (few x$10^{1\text{-}3}$) used in lockstep to calculate same algorithm with different inputs
- Programmed via special API
  - CUDA, OpenCL, OpenGL

GPU – Example CUDA code



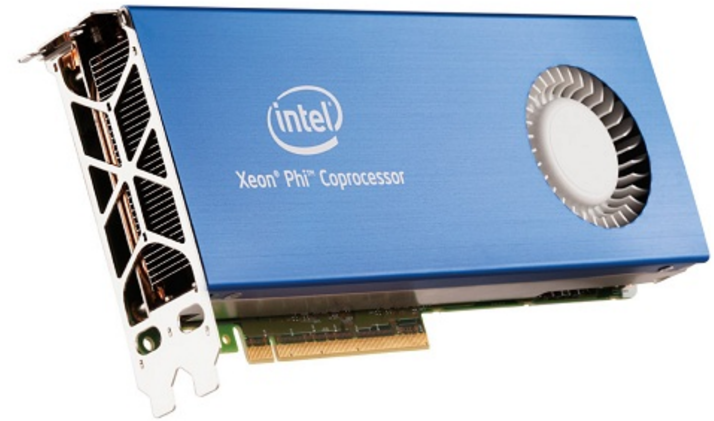
Standard C Code

```c
void saxpy(int n, float a,
           float *x, float *y)
{
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}

int N = 1<<20;


// Perform SAXPY on 1M elements
saxpy(N, 2.0, x, y);
```

C with CUDA extensions

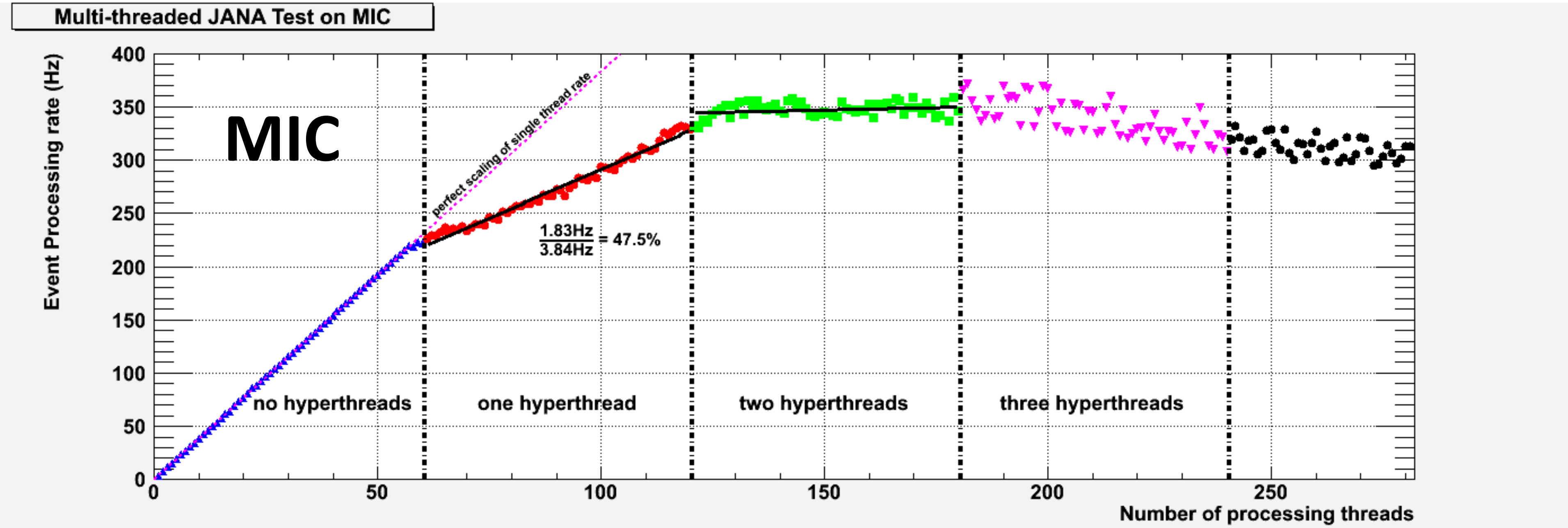
```c
__global__
void saxpy(int n, float a,
           float *x, float *y)
{
  int i = blockIdx.x*blockDim.x + threadIdx.x;
  if (i < n) y[i] = a*x[i] + y[i];
}

int N = 1<<20;
cudaMemcpy(x, d_x, N, cudaMemcpyHostToDevice);
cudaMemcpy(y, d_y, N, cudaMemcpyHostToDevice);

// Perform SAXPY on 1M elements
saxpy<<<4096,256>>>(N, 2.0, x, y);

cudaMemcpy(d_y, y, N, cudaMemcpyDeviceToHost);
```

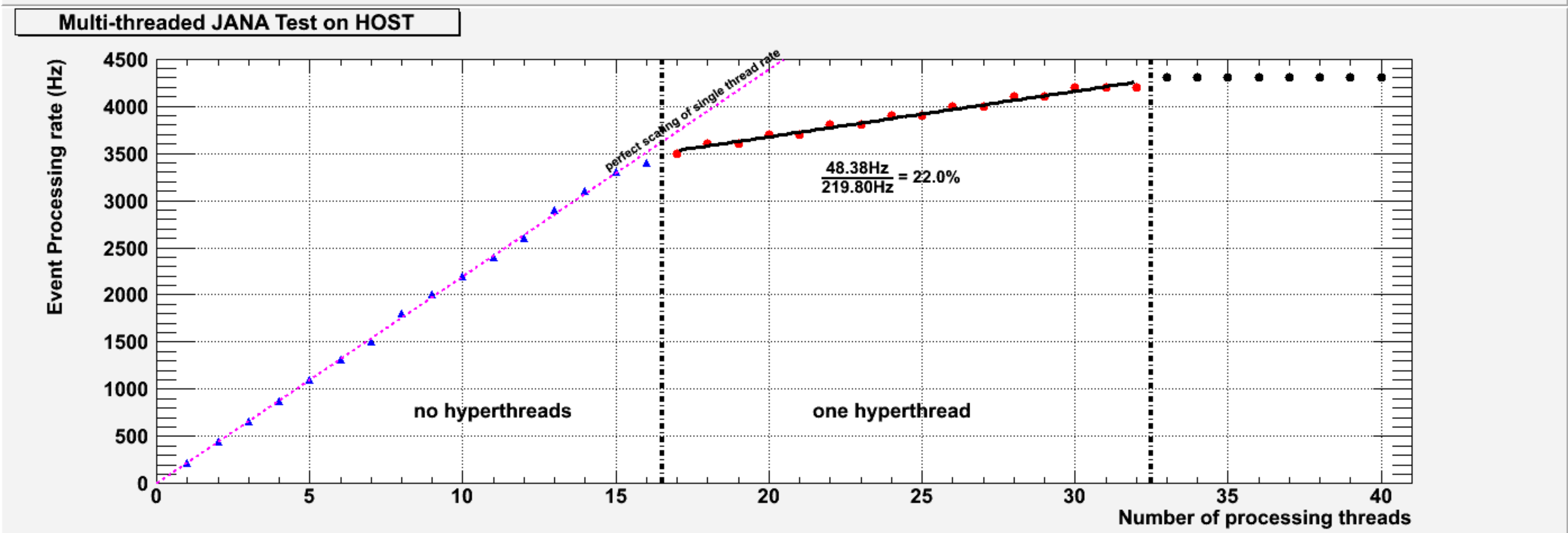
MIC = Many Integrated Cores



- Xeon Phi = Intel’s MIC system
  - 60 cores, 1GHz on a PCIe x16 card
  - 512 bit wide vectors
  - Original project: Larrabee
    - Attempt to make GPU from older x86 design
- Linux variant runs on MIC card independent of host OS
  - MIC system is based on 2.4 Linux kernel
  - File system not automatically shared
    - MIC cards can be configured to mount host’s filesystem via NFS
- Must use intel-provided cross-compiler to build executables
  - Could not build sim-recon because ROOT was needed
  - Could not build ROOT because libX11-devel was needed

Performance using JANA TestSpeed plugin





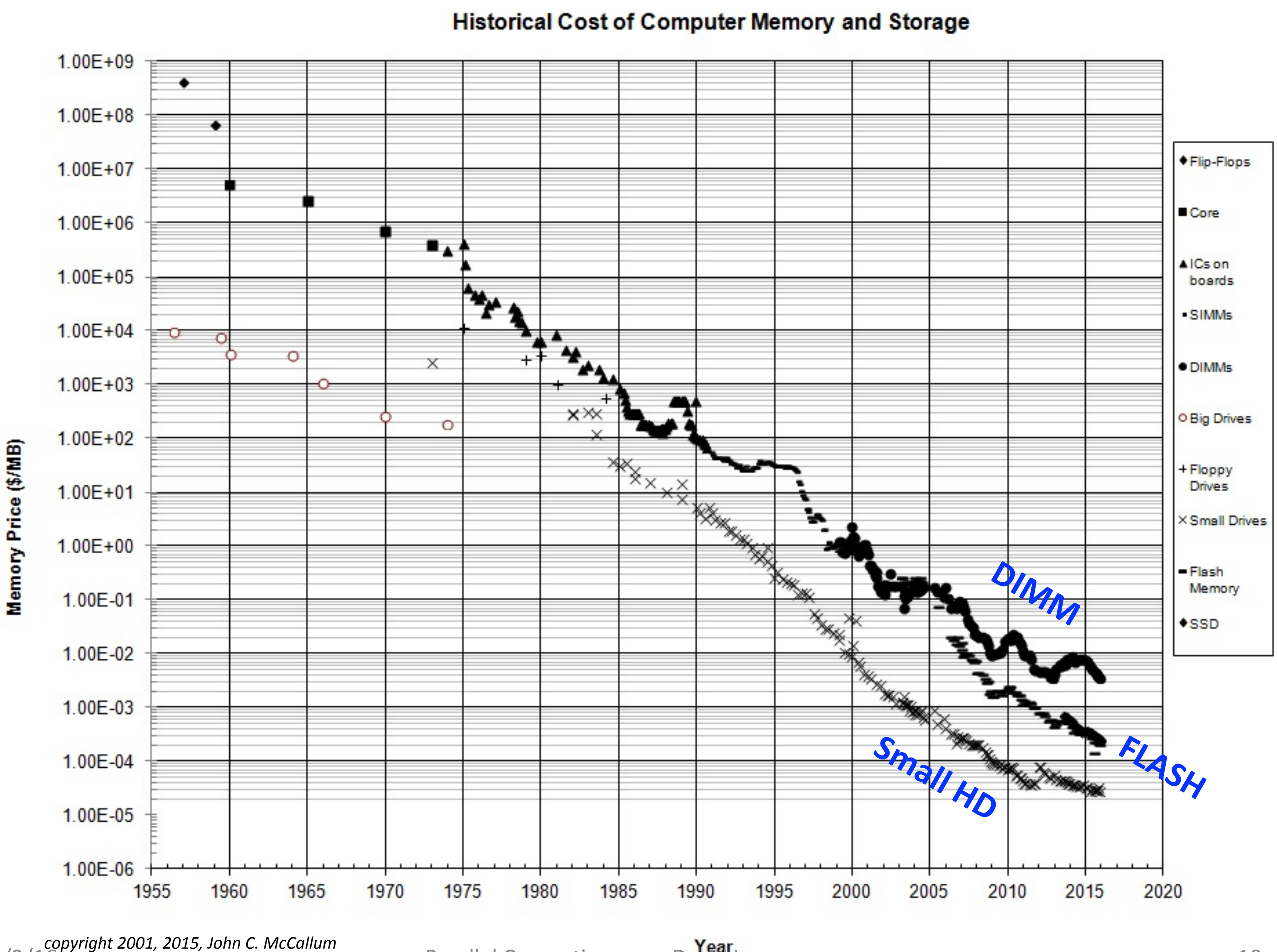
Multi-Threading vs. Multi-Process

Multi-threaded

- Uses same memory space
- Uses less RAM
- Minimizes disk head thrashing
- Less overhead in process management

Multi-process

- Uses special shared memory segments or other message passing protocol
- Independent program contexts
- Simpler to debug single thread program crashes
- Less expertise required by novice programmers



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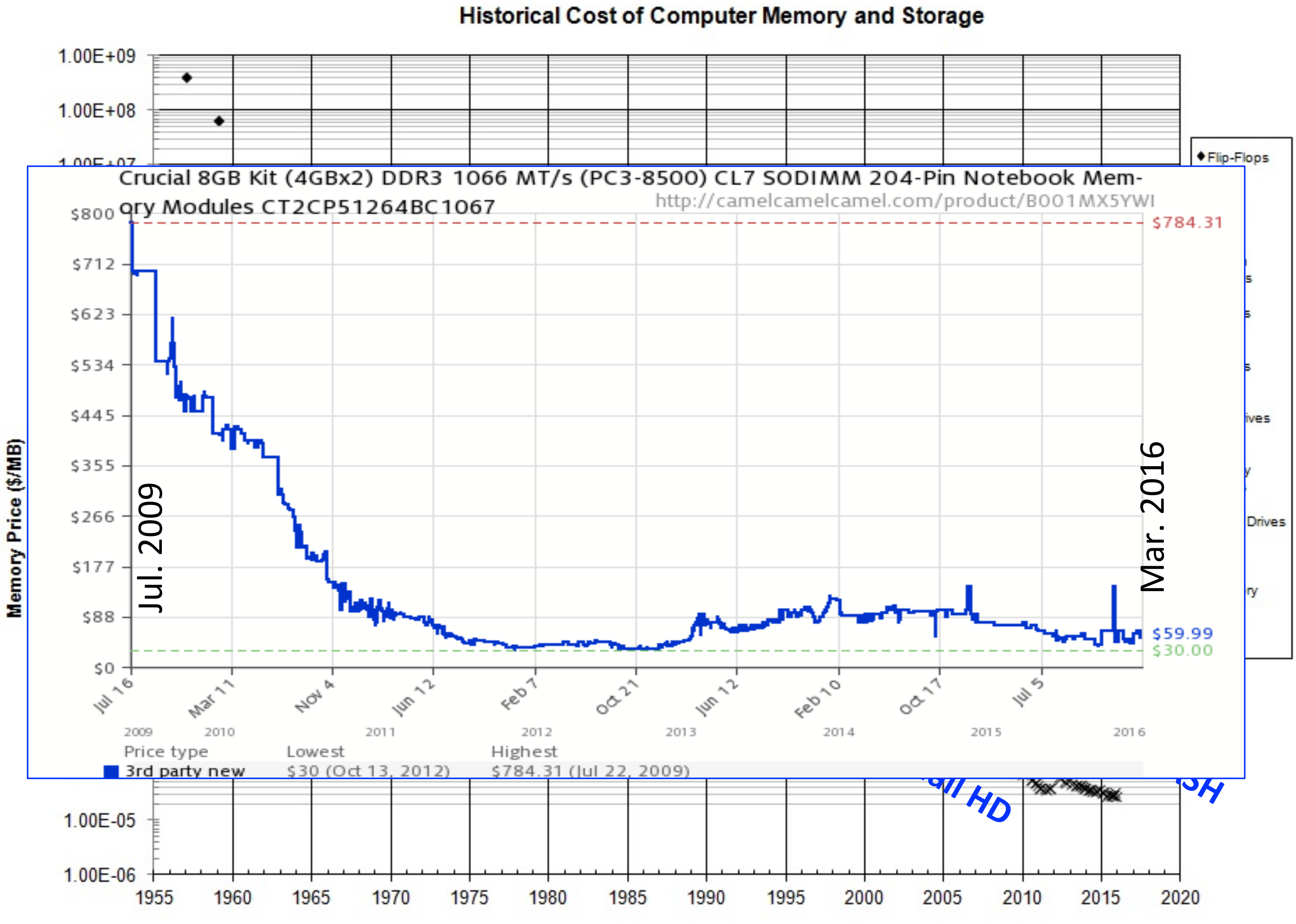

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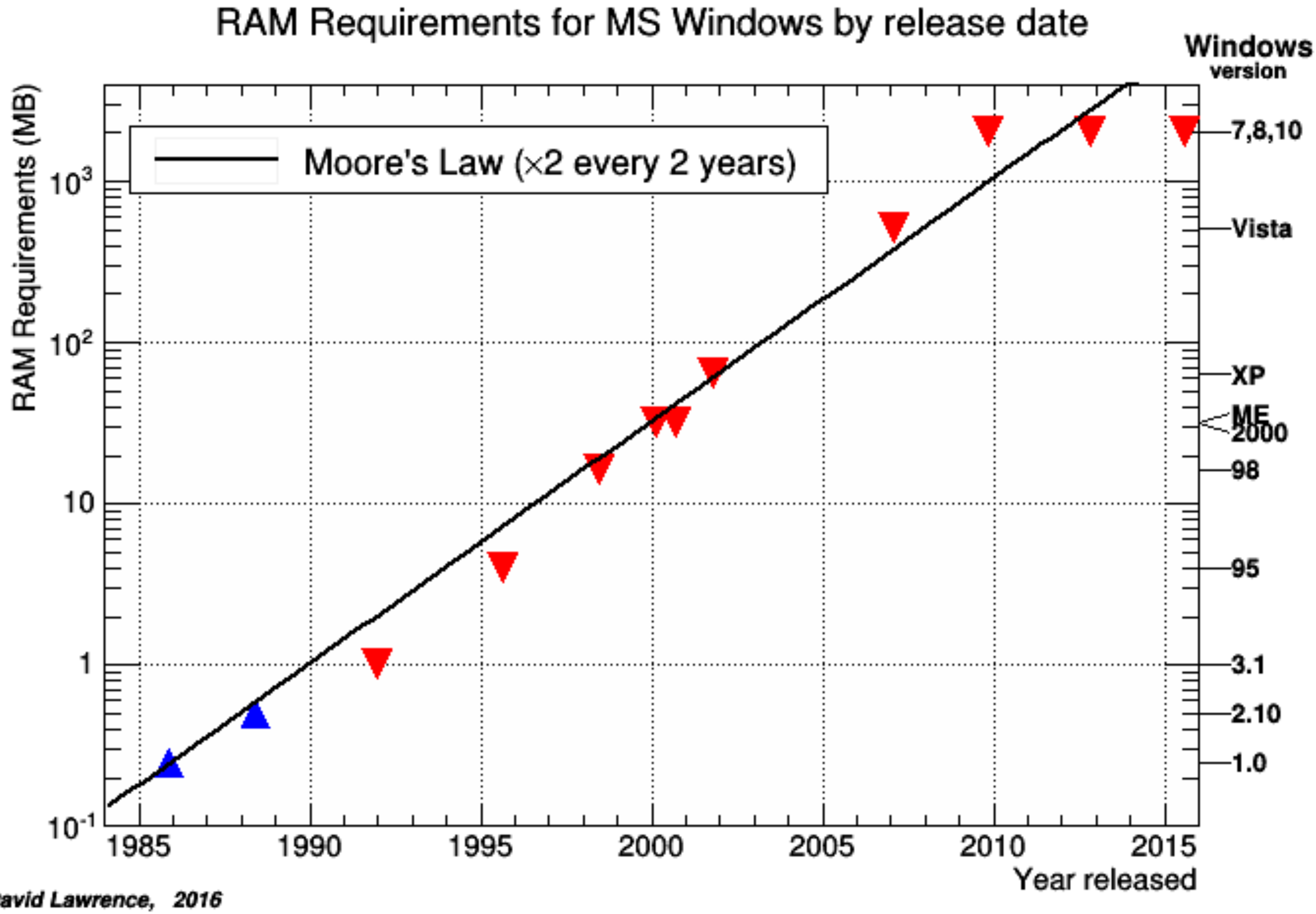
RAM Requirements for MS Windows by release date
Windows version
Moore's Law (×2 every 2 years)
RAM Requirements (MB)
10^3
10^2
10
1
10^-1
1985
1990
1995
2000
2005
2010
2015
Year released
7,8,10
Vista
XP
ME
2000
98
95
3.1
2.10
1.0
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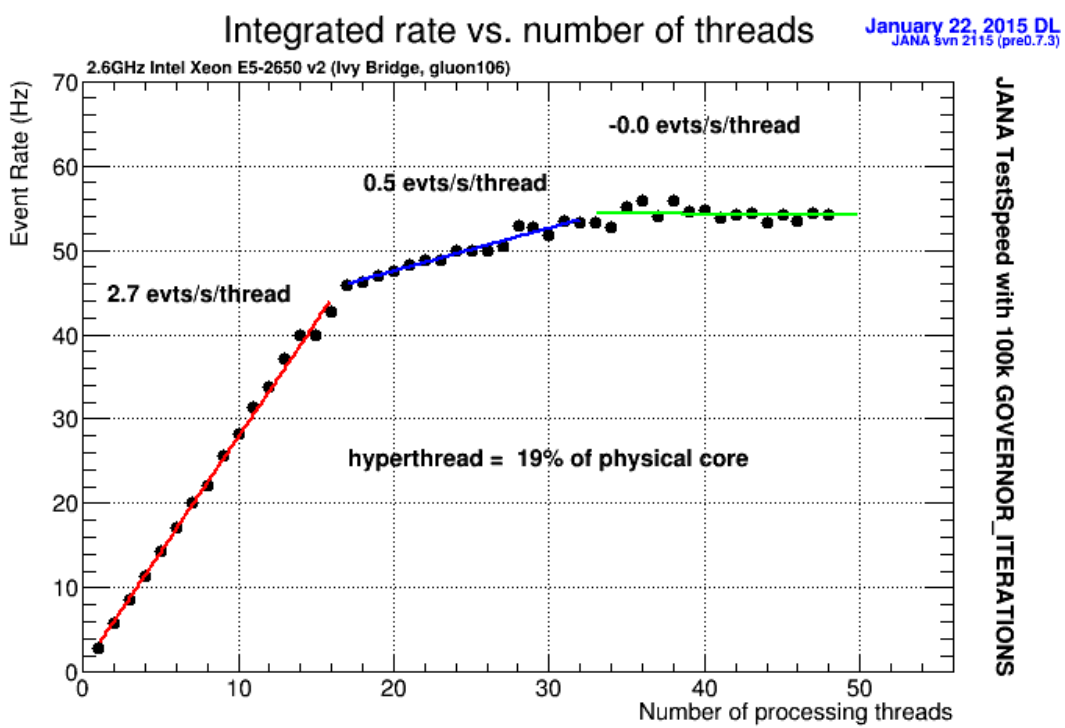
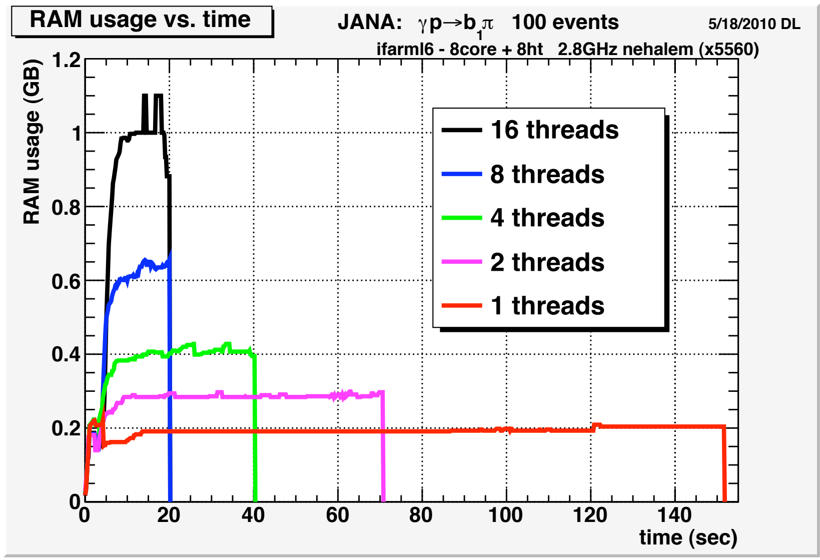
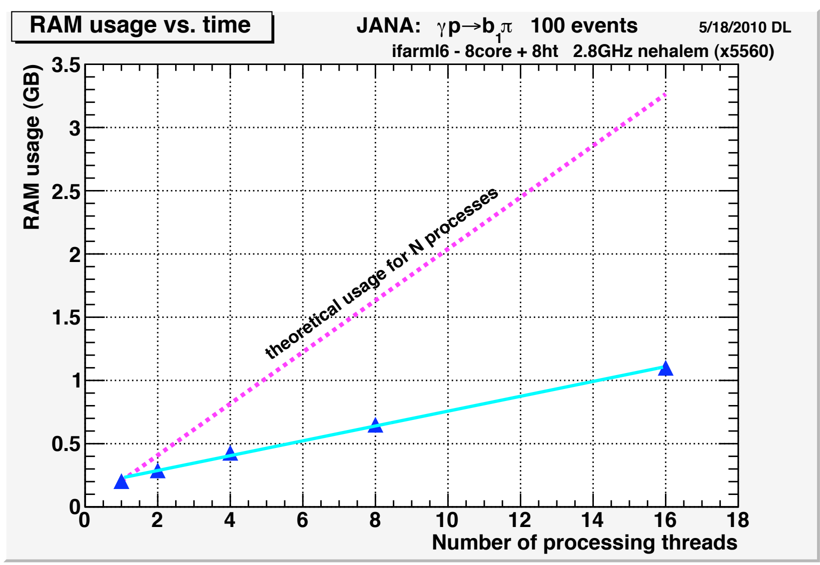
JANA rate scaling for CPU intensive task



JANA RAM usage



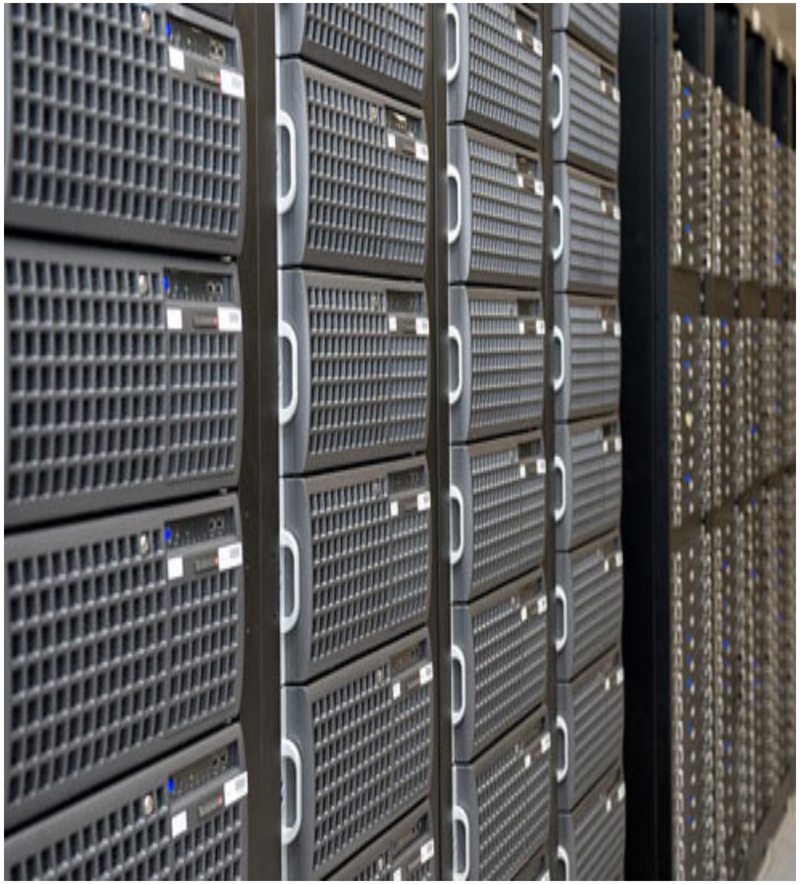


Multi-threaded GB/thread is about 1/3 that of multi-process

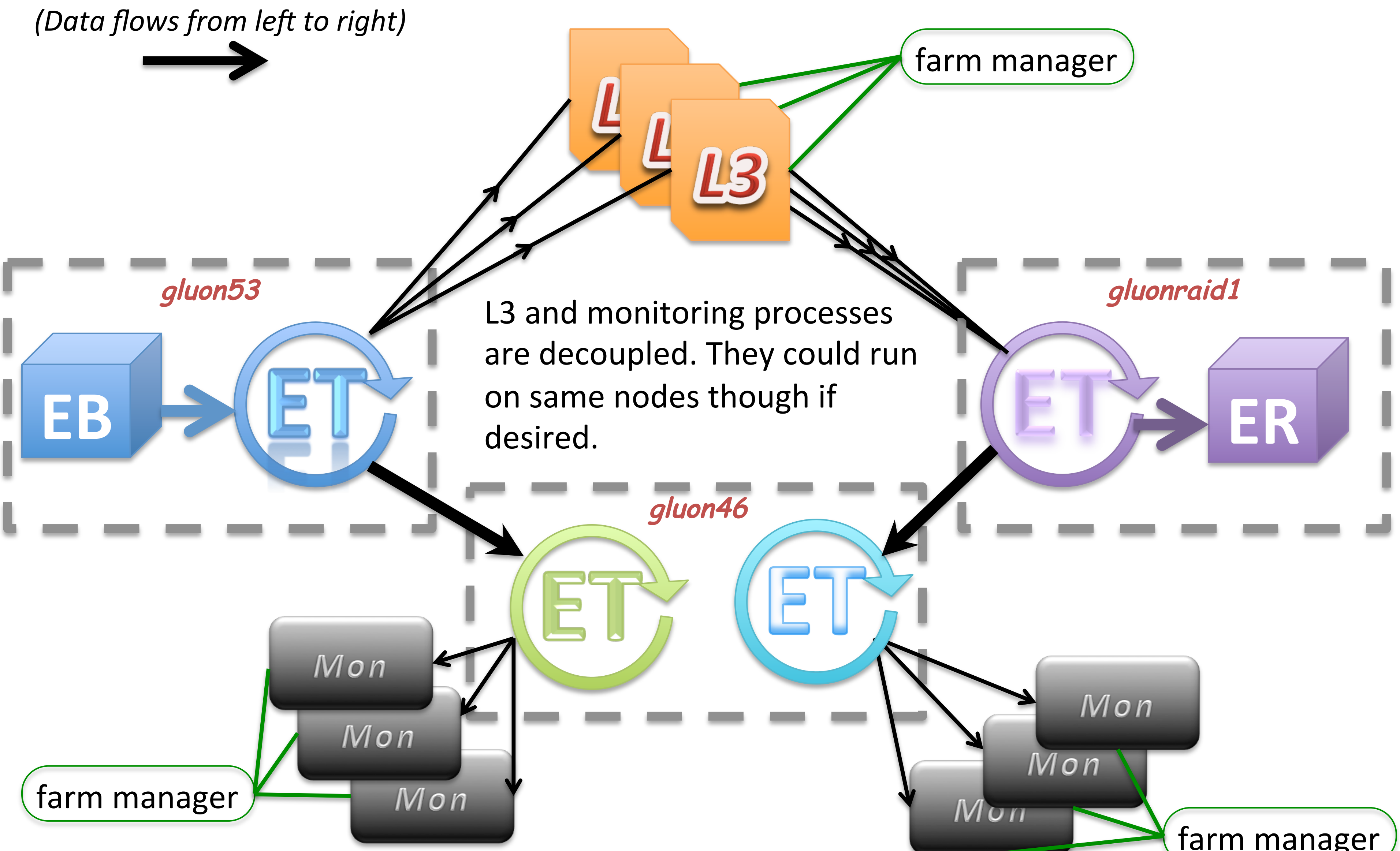
Distributed Computing

(Let's just call it "farms")

- large cluster of computers, housed in same location, and connected via fast LAN
- jobs run independently on single node *(… or maybe not …)*
- focuses significant compute power to dedicated job
- "clouds" tend to be made up of multiples of these connected via WAN



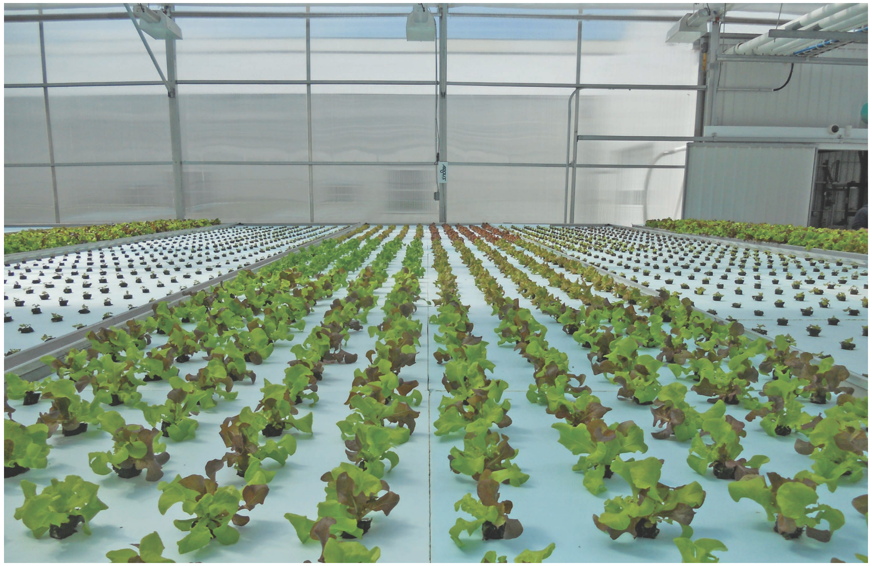
Hall-D L3 and monitoring architecture



Farms in the Future

Farms will play a role in the future due to power supply and dissipation

(i.e. You can't pack too many teraflops into a small volume without burning everything up!)



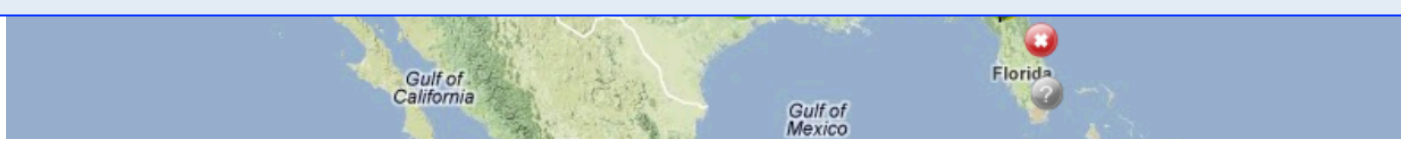
Open Science GRID

- US-based federation of compute infrastructures for research and academic communities

Open Science GRID

Characteristics of OSG Jobs

- **The application is a Linux application for the x86 or x86_64 architecture.**
- **The application is single- or multi-threaded but does not require message passing.**
- **The application has a small runtime between 1 and 24 hours.**
- **The application can handle being unexpectedly killed and restarted.**
- **The application is built from software that does not require contact to licensing servers.**
- **The scientific problem can be described as a workflow consisting of jobs of such kind.**
- **The scientific problem requires running a very large number of small jobs rather than a few large jobs.**



What do big LHC Experiments Do?

- CMS
  - Initially developed reconstruction algorithms as single-threaded
  - Developed framework that can identify which algorithms can be run in parallel giving sub-event level parallelism
- ATLAS
  - Single threaded using GAUDI
  - Developing GAUDIHive for parallelism at event, algorithm, and sub-algorithm levels

What do RHIC Experiments Do?

- Who knows?
  (Online documentation is quite old)

What to plan for? (IMHO)

- Parallelism will play a role. Effective systems will likely take advantage of multiple technologies
  - Tough to tell what emerging technologies will stick around. *(Be careful, but not overly cautious!)*
  - Spend time on the API. It will allow parts of the software to be replaced later without rewriting everything
  - Stay away from requiring commercial products (libraries). Stick with Open Source
  - Commit resources to software R&D. Not just at the beginning, but continuing…

Additional Thoughts (IMLTHO)

- The accessibility of a computing technology should be inversely proportional to the developer base *(i.e. if you commit everyone to an obscure or expensive technology, a lot less people we be able to contribute)*
- We have an obligation to next generation students/scientists to engage them in technologies that carry them at least a little way into the future as opposed to holding them in our past

Backups

Farms in the Future

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