SIGGRAPH2015

Xroads of Discovery

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The 42nd International Conference and Exhibition on Computer Graphics and Interactive Techniques

DreamWorks
the dream is everything

Parallel evaluation of character rigs using TBB and vectorization

Martin Watt
DreamWorks Animation

Overview

Threading

Parallel graph design

Vectorization

Applied to animation graphs

Hardware challenges

eg CPU Power modes, Hyperthreading, Turbo Boost, Memory, NUMA

Lessons learned - all of the above

Premo


Premo sq325
s22
s23
s24
s25
s26
101
Property of Dreamworks Animation

Motivation

Existing animation tool (EMO) unthreaded so not getting faster.

Complexity of characters continues to increase

Too difficult to retrofit existing tools with threading

Need to build new tools and new engine for scalability

Goals

Much faster evaluation - interactive manipulation of character rigs

Immersive workflows, a fluid artist experience

High quality display of full resolution characters and environments

Character workload

Motion system (bones)

- 100s to 1000s of relatively lightweight nodes

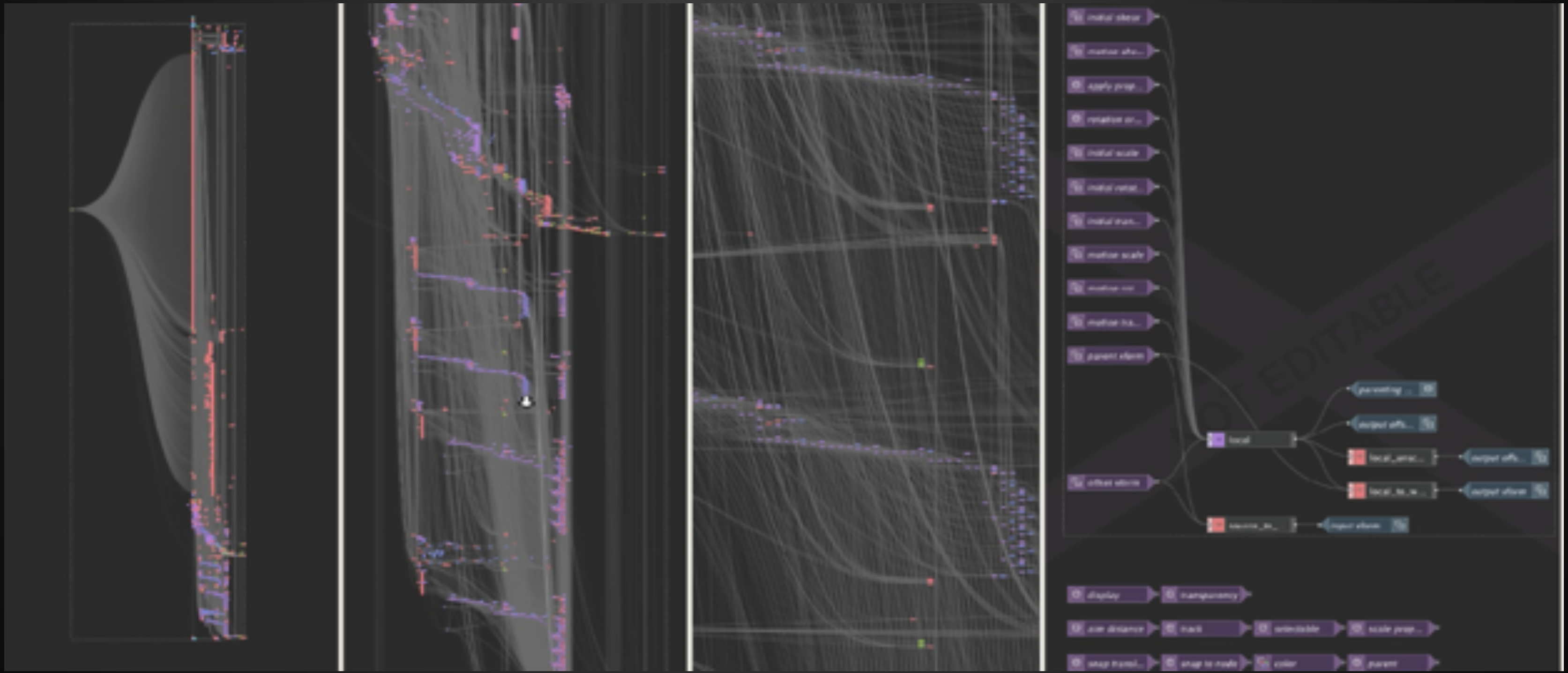
Deformation system (skin, muscle)

- 10s of heavier nodes
- ~1 million vertices on meshes

Effects (Cloth, hair, fur)

- Very expensive nodes

Hero Rig dependency graph
(150k nodes)



Character animation features

Character graph has natural parallelism
eg limbs usually independent

Some heavy nodes (eg deformers/solvers)
Use internal threading, so require nested threading support

Require real time (>10fps for thousands of nodes)
Scheduling and graph traversal overhead needs to be very low

Evaluation mechanism

Dependency Graph

Traditional DG has two pass evaluation

- Dirty propagation
- Pull evaluation (recursive, hard to parallelize)

Libee has three pass evaluation

- Dirty propagation
- Upstream traversal to determine dirty nodes to recompute, tag dependencies
- Final pass evaluating nodes concurrently

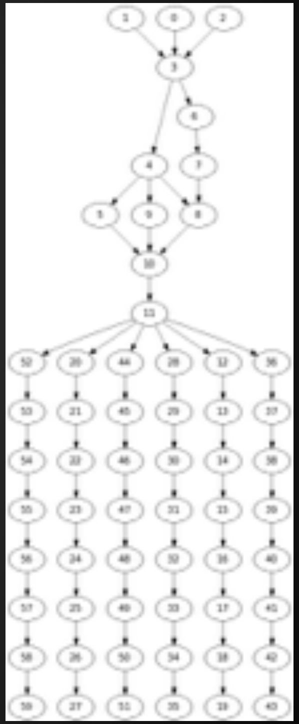
Evaluating graphs efficiently

Graph is evaluated each frame

- Typically thousands of nodes and edges
- Need to evaluate in tens of milliseconds

Multithreading can help performance

- Nodes can be executed in parallel
- Question of the best approach to use



Low level threading

Could potentially use native pthreads

- Create graph partitions
- Manually assign partitions to threads

However, graph partitioning is a hard problem

- Suitable partitions may take longer to compute than frame time
- Want solution that can quickly adapt to graph changes

Also, pthreads are not good for nested parallelism

- Some nodes might exploit parallelism internally

Would like the threading at different levels to work together

Higher level threading

OpenMP does not handle nesting well

Threading Building Blocks (TBB) solves our issues

- Supports nested parallelism
- Reasonably low overhead

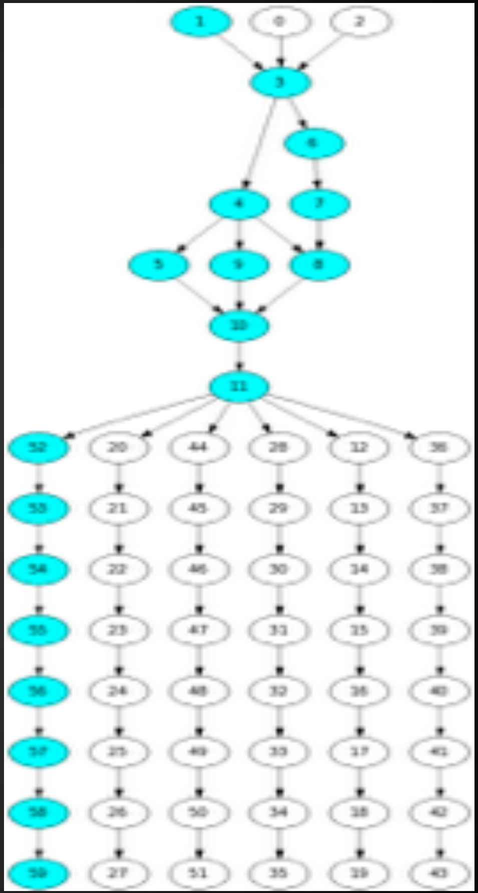
Each thread has a task pool

- Idle threads steal work
- Provides load balancing

Serial evaluation

Evaluate only nodes that are necessary

- Artist may not modify all controls
- Not all outputs may be visible



Parallel evaluation

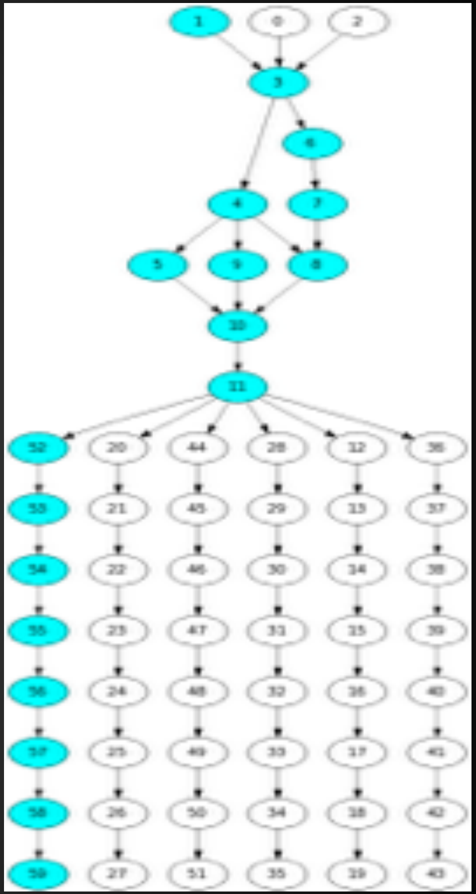
List of nodes is no longer sufficient

- Parallelism removes ordering guarantees
- Must track dependencies between nodes

A node with ready inputs is enabled

- Corresponds to spawning of TBB task
- The task will be executed at some point

Tasks also spawned for internal parallelism



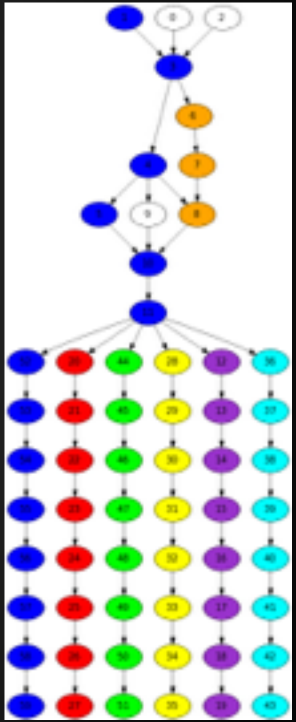
Chaining optimization

One task per node creates high scheduling overhead

Over 75% of nodes are in chains

Group serial chains of nodes into single TBB task

- Reduces threading scheduling overhead
- Improves cache locality



Rig evaluation ordering

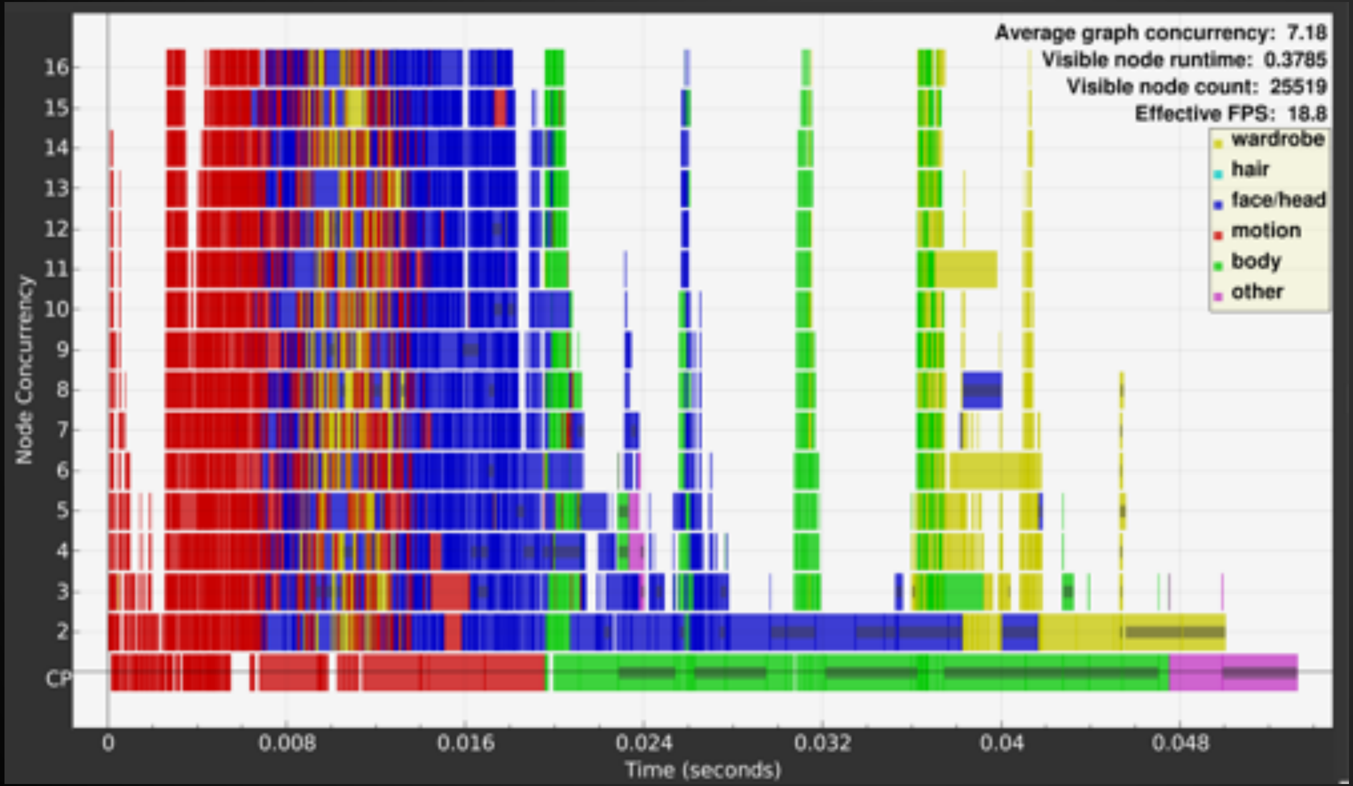
Need to order dependencies to enable parallelism

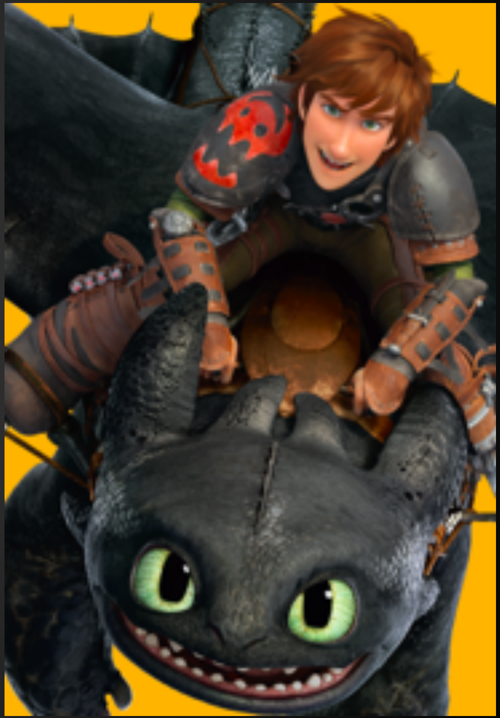
Riggers need to become thread-aware

Took us way too long to realize this

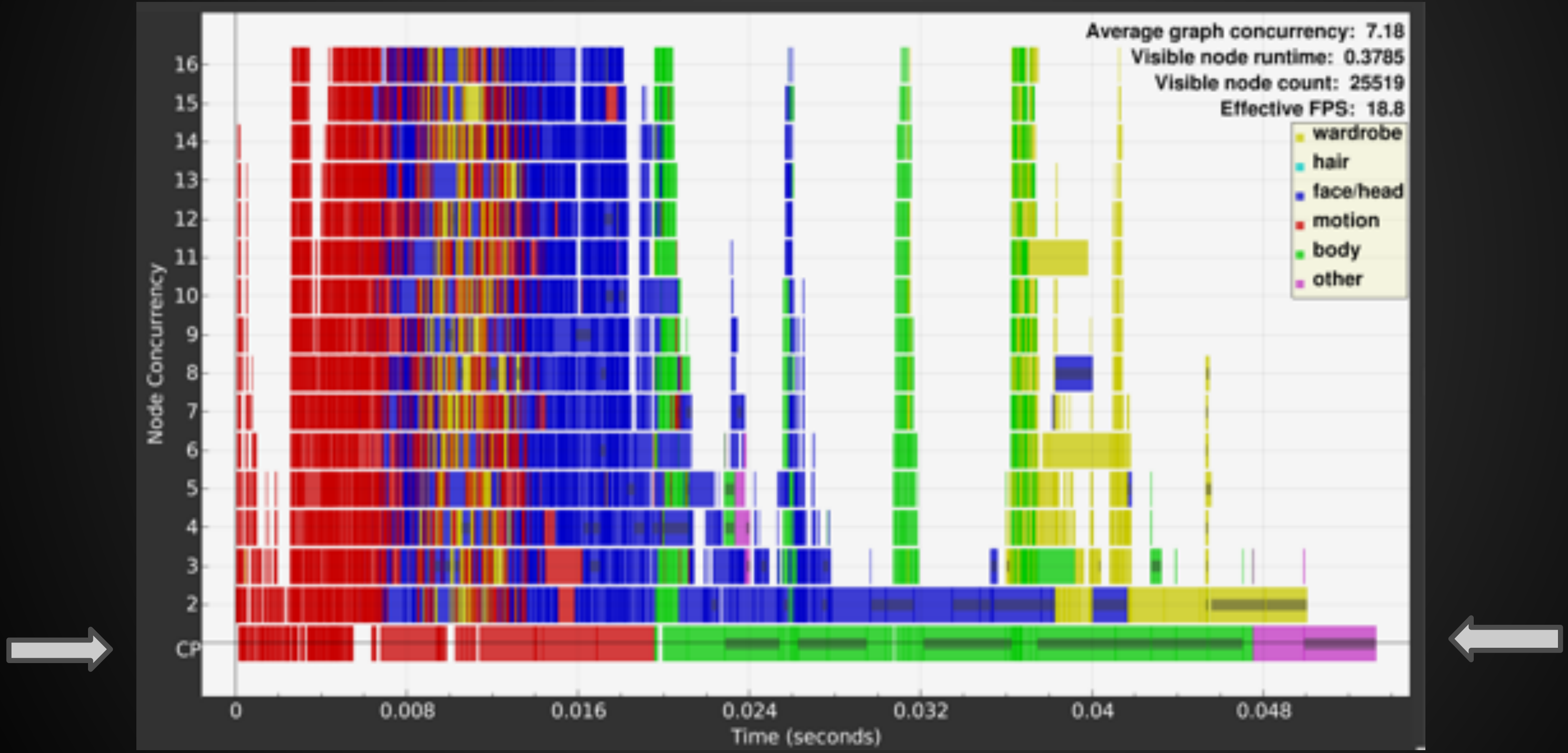
Finally created tool for riggers to show graph eval

Parallel view (Hiccup, HTTYD2)



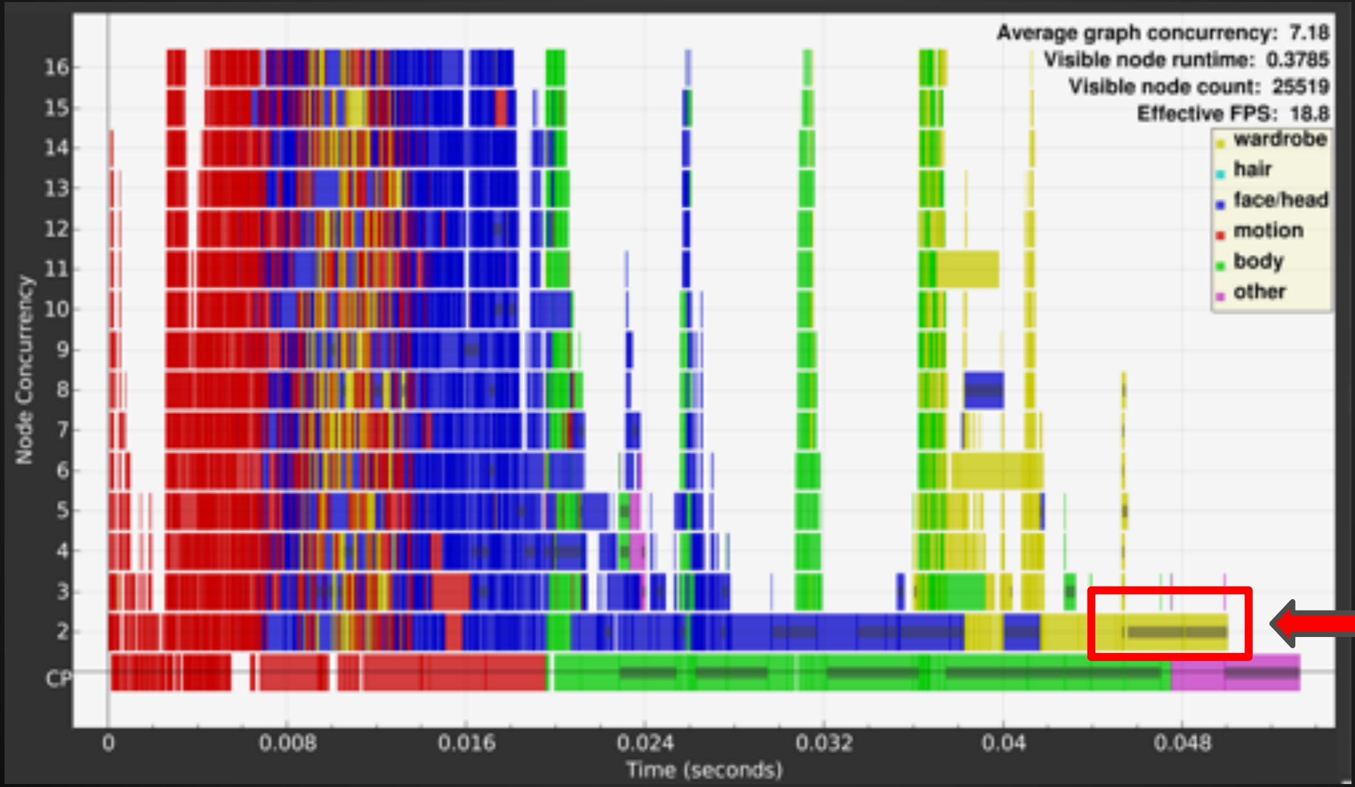


Critical path most important



Others less important

Focus limited resources on critical path

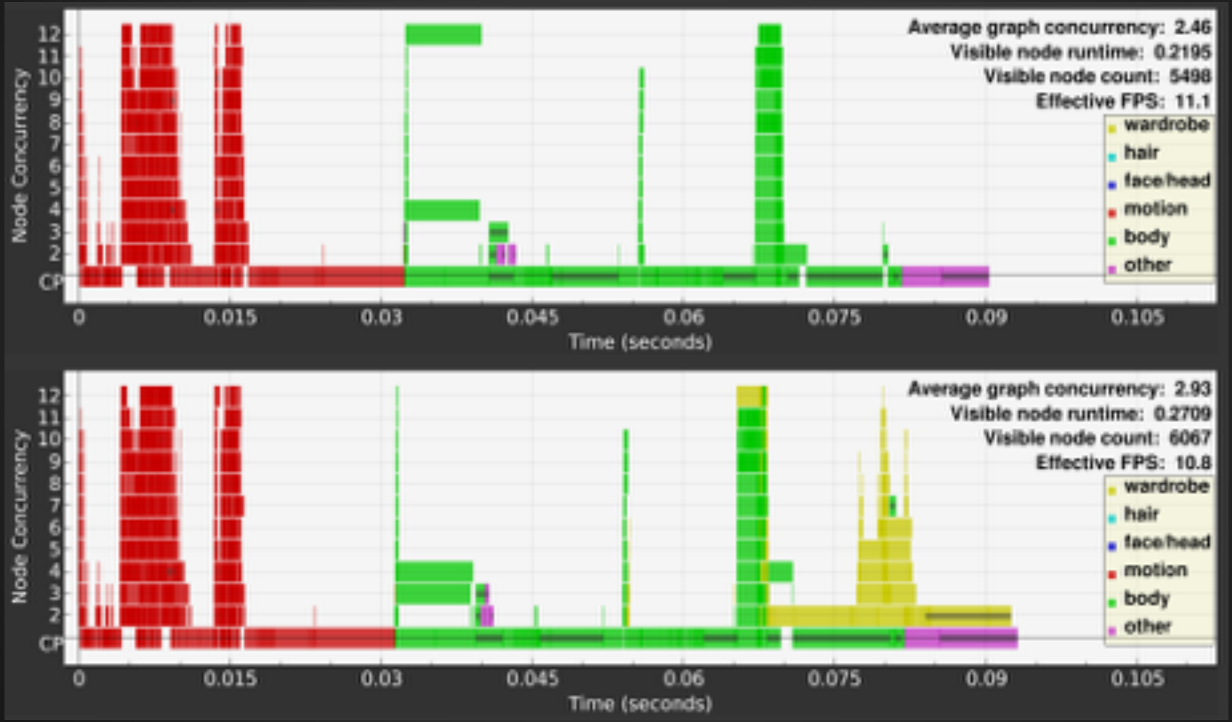


Don't start here even if most costly node in graph

Reordering evaluation

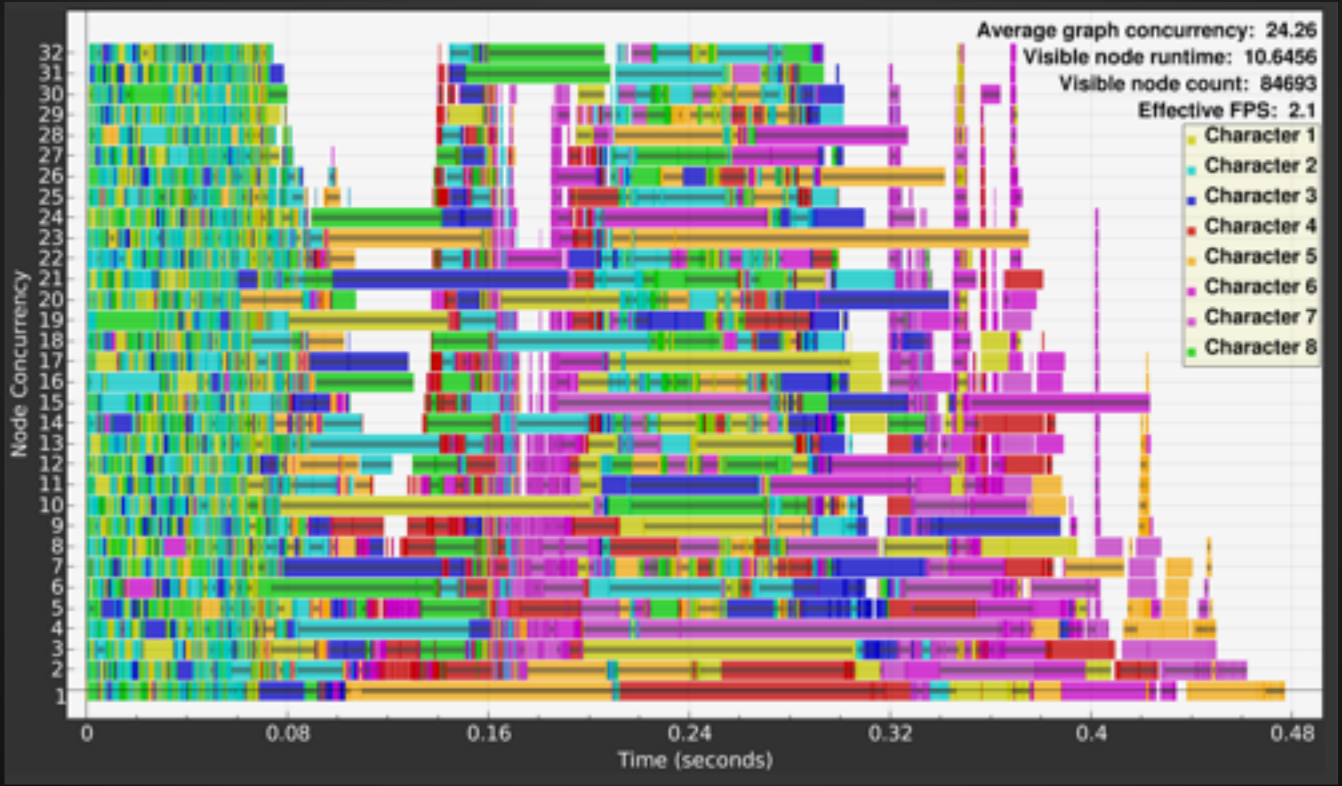
Manual parallel evaluation

(Almost) free clothing!



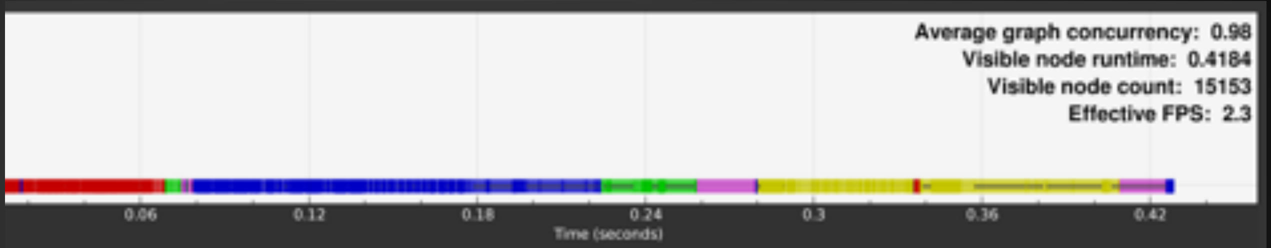
Critical path does slow down a little as other concurrent tasks are added

Multiple characters

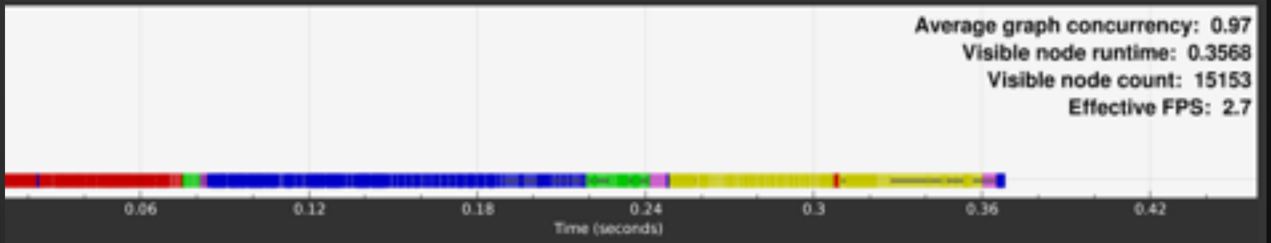


Most benefits at graph level

None



Node



Graph

Threading challenges

R&D and artists can author operators

Engine is new, but code running in nodes is often old

Operators can call into arbitrary studio code

Code can be running concurrently even if not threaded

- Need to think about threading even if not ‘threading’
- Parallelism exists at higher level than algorithm

Approach

Clean up studio code

Significant effort

Review

Adopt review process for new nodes to validate for threadsafety

Validation

Parallel unit tests
Code review
Compiler flags
Thread checking tools

Additional restrictions imposed

No scripting languages, eg Python, in-house scripting languages

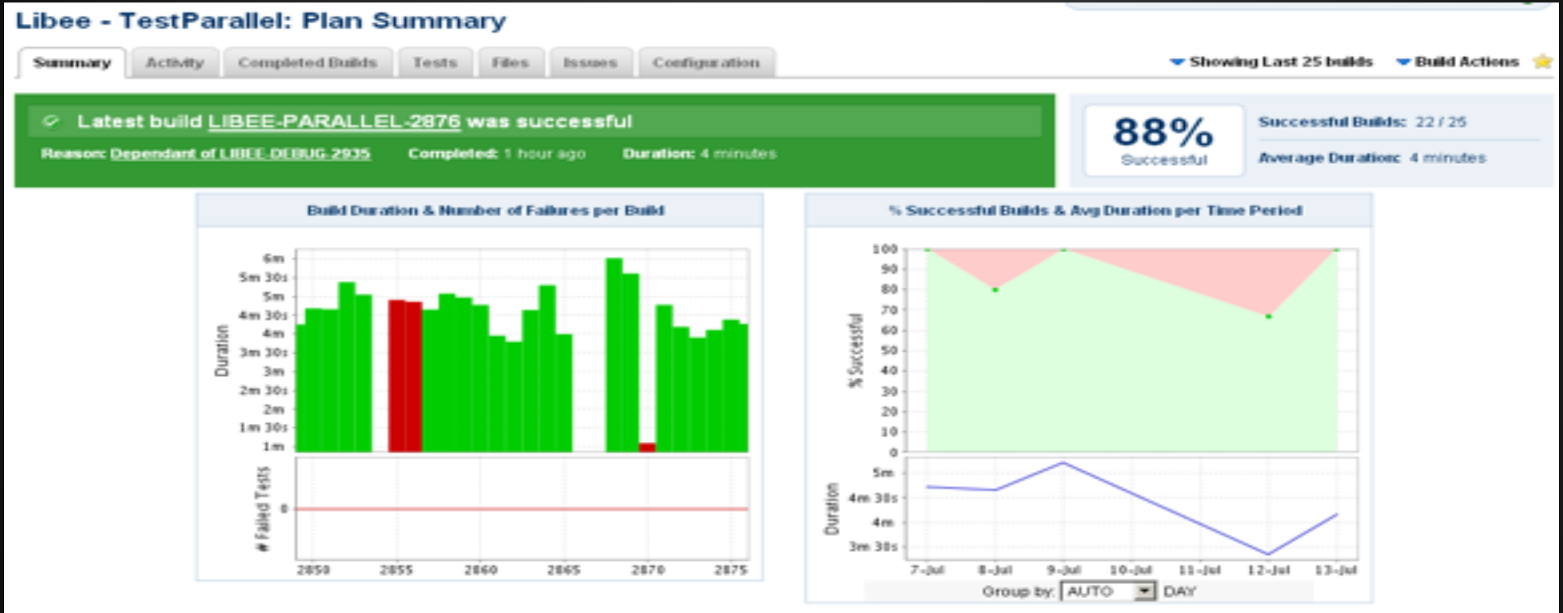
- Too slow, not threaded
- Concern for riggers, easier to use script-based nodes

Nodes cannot directly access other nodes

- For example expression nodes that query other node attributes disallowed

No loops in the graph

Keeping code threadsafe



Parallel unit tests run 24/7

Intermittent failures show possible threading bugs

TBB locks - be careful

```
tbb::spin_mutex mutex;

{
    tbb::spin_mutex::scoped_lock(mutex);
    [non-threadsafe code]
}
```

What is wrong here?

TBB locks - be careful

```
tbb::spin_mutex mutex;

{
    tbb::spin_mutex::scoped_lock(mutex);
    [non-threadsafe code]
}
```

No named object to persist!
Lock destructs at semicolon, code is unprotected

TBB locks - be careful

```
tbb::spin_mutex mutex;

{
    tbb::spin_mutex::scoped_lock  myLock(mutex);
    [non-threadsafe code]
}
```

TBB locks - be careful

This happened at DreamWorks multiple times.
Even to extremely experienced engineers.

TBB locks - be careful

How did we find it?

Enabled stricter compiler warnings:

```
>icpc -c main.c           // before - no warnings

>icpc -w3 -c main.c       // enable strict warnings -w3
remark #3280: declaration hides variable "mutex" (declared at line 3)
    tbb::spin_mutex::scoped_lock(mutex);
```

Different warning but does point to the problem, somewhat luckily

Thread local storage

C++11 keyword

Useful when state persists beyond scope of method, eg in legacy C code.

```
thread_local double tolerance = 1e-9;

void setTolerance(double tol) {
  tolerance = tol;
}

void evaluate()
{
  evaluateStuff(tolerance);
}
```

Less needed in C++ - use class scope

Thread local storage problems

Limited in size. Can run out.

Limited in number of libraries allowed (16)

`dlopen: cannot load any more object with static TLS`

Have custom Linux glibc patch from RH to increase limit!
(Bumped up in RHEL7.x)
https://bugzilla.redhat.com/show_bug.cgi?id=1124987

TLS not really recommended. More of a band aid.

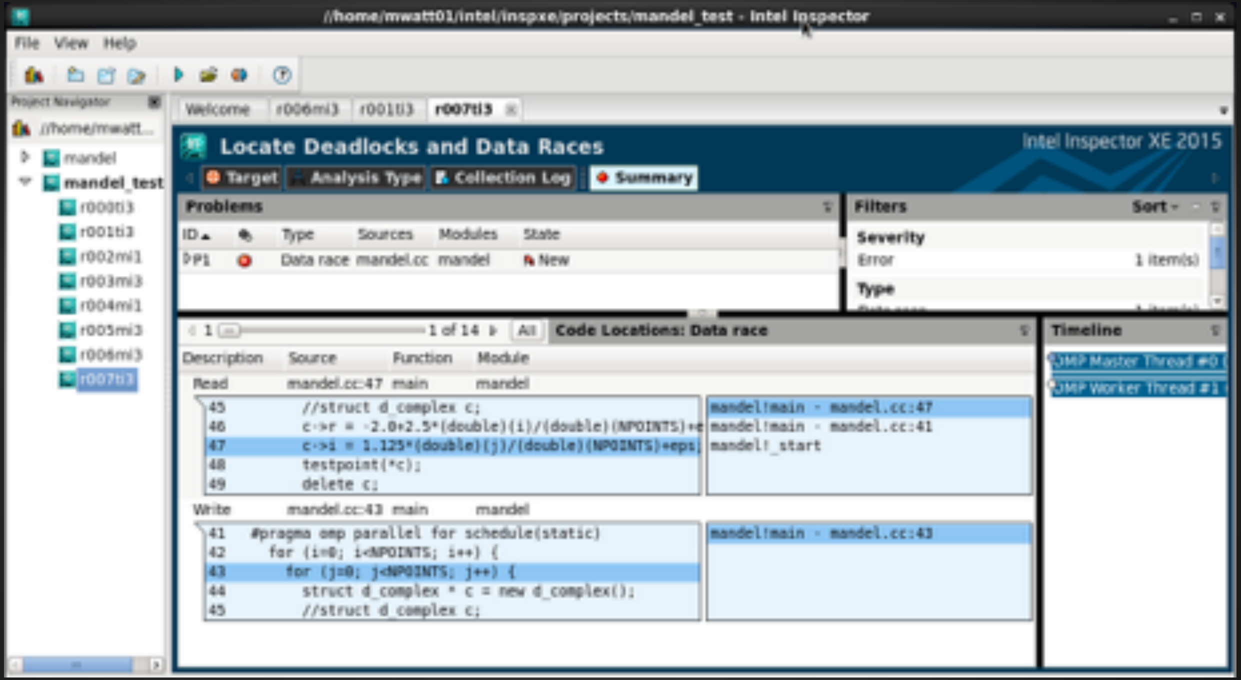
Memory allocators

Need a thread-friendly allocator, unless/until remove mallocs

Using TBB’s memory allocator, tbb_malloc

- Performs well.
- Occasional pathological behavior with incrementally growing reallocs.
- Slightly better than jemalloc for Premo, but YMMV

Intel Inspector



Can be useful, but sometimes a lot of false positives

Vectorization

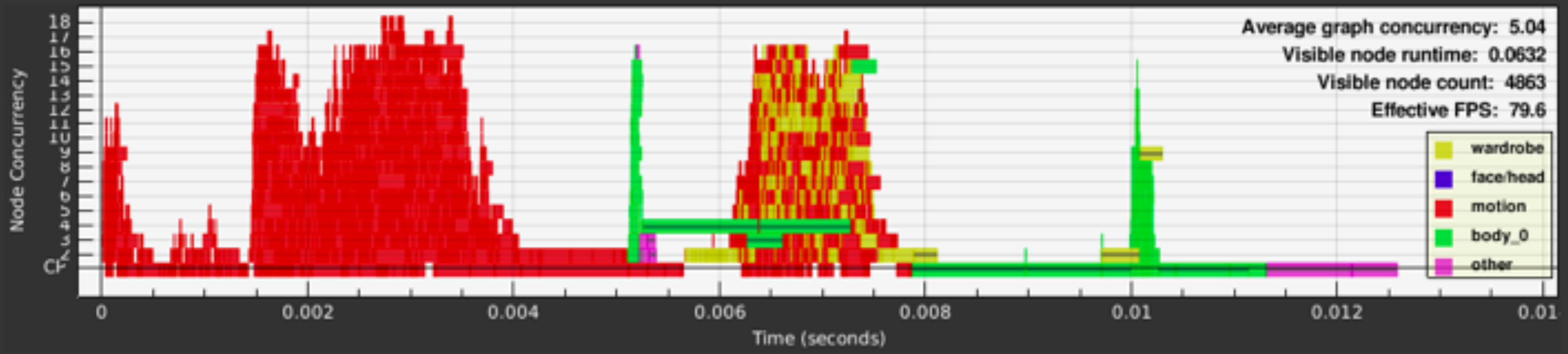
Threading offers largest initial gains

- First version of LibEE incorporates threading

Next look at vectorization

- Heavy compute nodes, eg deformers

Vectorization - starting point



Deformers <50% of runtime (green nodes above)

Amdahl-like law applies here too. Limited benefits for this example

Rig optimization procedure

Want to vectorize deformers

- Only ~30% of eval time
- Skeleton takes >50% of time

So… optimize skeleton first

- Optimize the non-vectorized part first

Motion system optimization first

Optimization:
Transform Building Blocks (XBB)

Avoid zero multiplies
(very common with matrices)

Link at end of this slide deck

No threading
No vectorization
1.6x faster

Programming SIMD

- Assembly
  - Really hard
- Intrinsics
  - Hard, locked in to specific vector instruction set
- Compiler autovectorizer
  - Safer
  - Portable
  - Maintainable
  - Tricky to guarantee vectorization

SIMD Building Blocks (SBB)

SIMD Building Blocks (SBB) is a C++ template library for vectorization offering:

- Containers, accessors, kernels, engines
- Optimizes code so compiler can autovectorize
- Handles data transformation & alignment
- Engine handles iteration
- Works with any C++11 compiler
- Enable transparent vectorization + threading (single threaded, TBB, OpenMP) execution of kernels.

“TBB for Vectorization”

Link at end of this slide deck

SIMD Building Blocks (SBB)

Generate efficient SIMD code by
    encapsulating in-memory data layout of objects
    isolating it from kernels.

Allows containers to transparently use an SOA data layout.

Provides methodologies that avoid common pitfalls to generating efficient SIMD code.

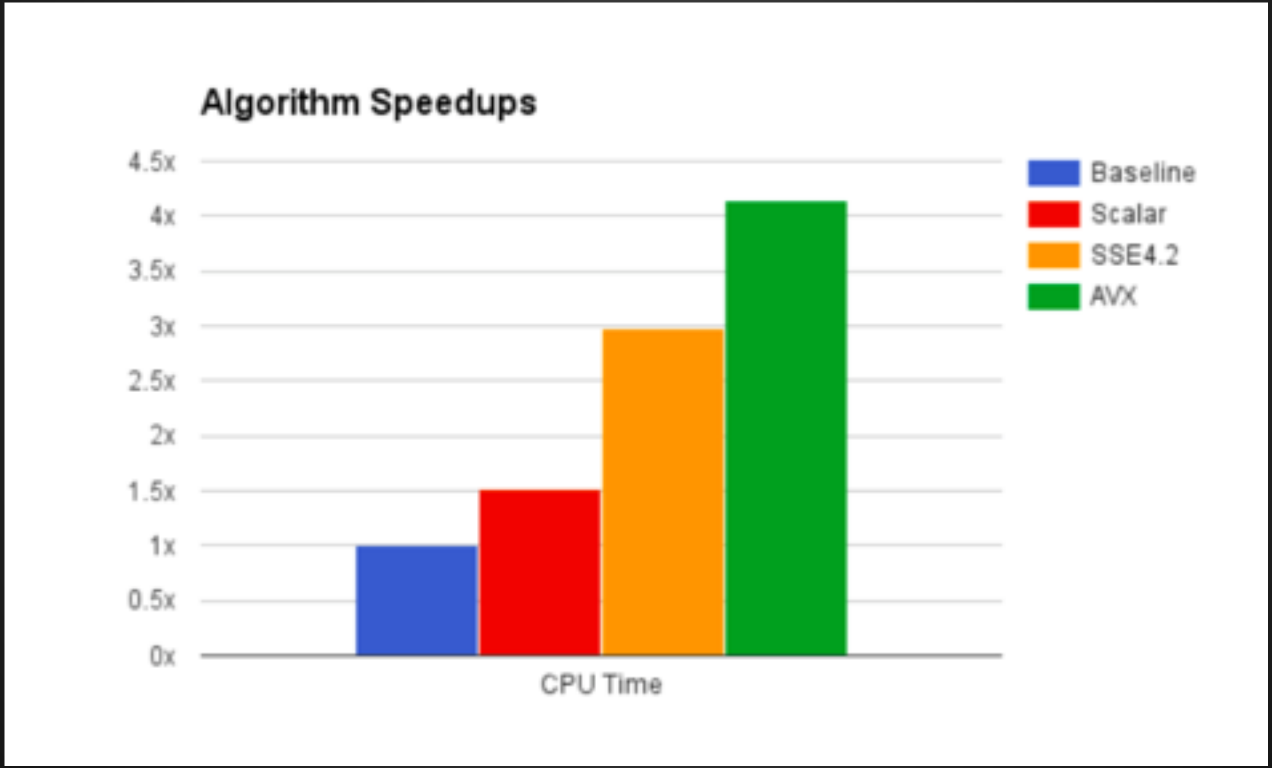
SBB compiler requirements

Need some C++11

No proprietary Intel compiler features are required

Other compilers may not generate vectorized code

Vectorization speedups



Overall speedup

Production Rig:

- Deformer: 4x faster
- Overall Rig: 10% faster

Two types of scaling

Amdahl's Law

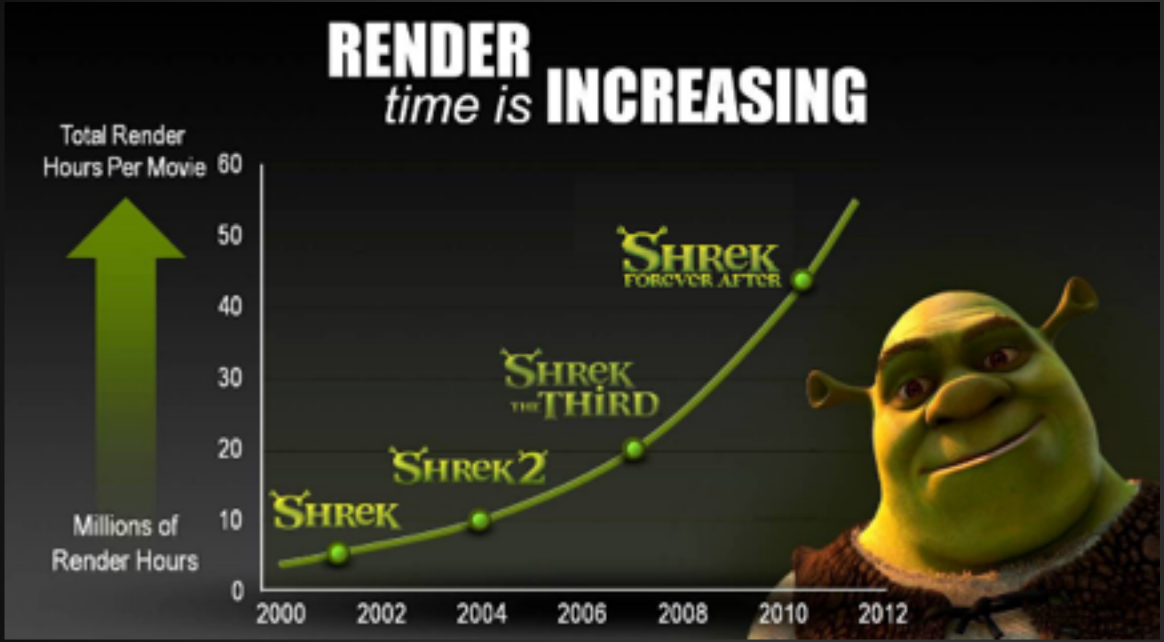
Same problem in smaller time

Gustafson's observation

Bigger problem in same time

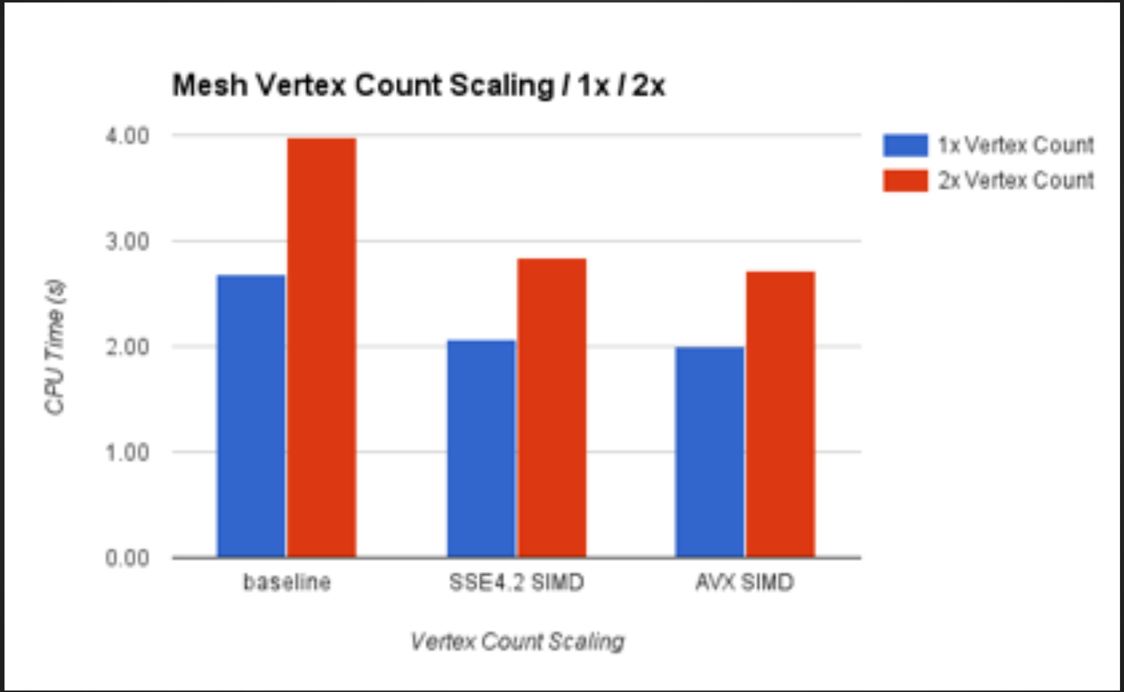
We are usually on the second of these

Complexity always increases



Shrek's Law

Increase workload



Can evaluate twice the mesh resolution in the same time

Overall speedup

Production Rig:

Deformer: 4x faster
Overall Rig: 10% faster

Scaled up production rig (2x resolution)

Deformer: 4x faster
Overall Rig: Same speed

Hardware issues

CPU Power modes
Hyperthreading
Turbo Boost
Memory Wall
Thread Affinity
NUMA
More cores vs more clock?

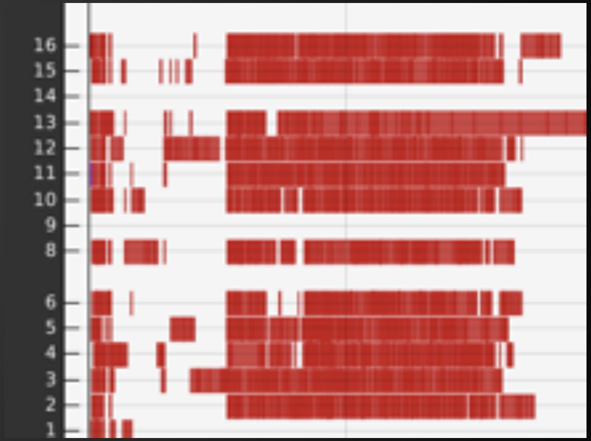
Power saving BIOS modes

Power saving vs performance mode

Found a big difference (~20%)

Problem is workloads are very bursty

CPU takes time to clock up



Other system activity

TBB assumes it has all cores available

Often one or more cores used for other purposes

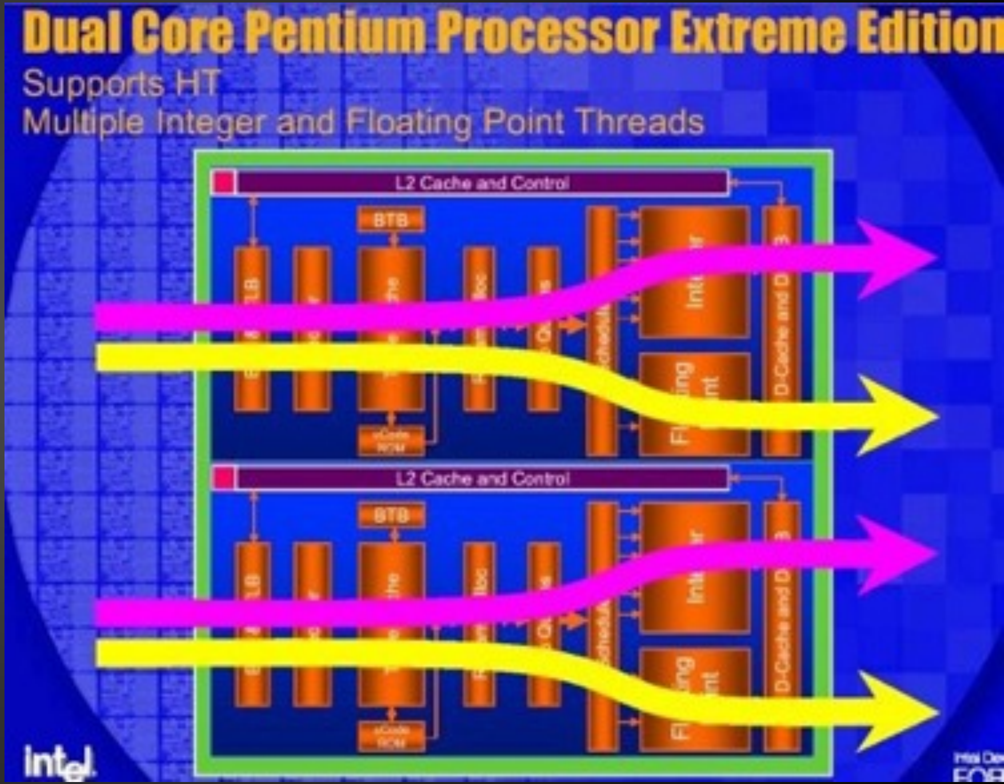
With higher thread counts, ok to give up 1 or 2 threads

Hyperthreading

One physical core

acts like

Two logical cores



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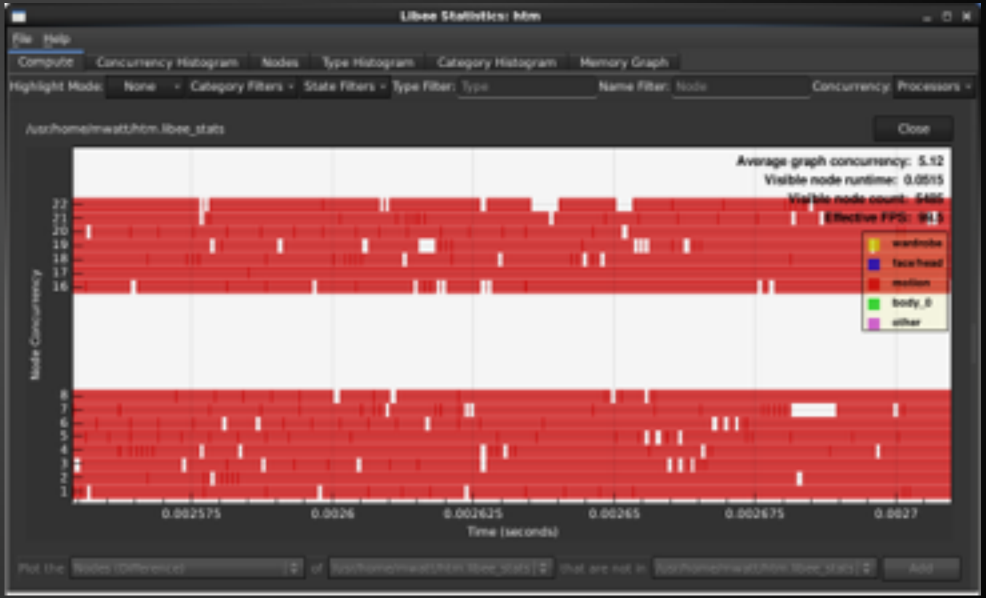
Hyperthreading: load balancing

More work than cores

Workload uses all logical cores

Benefits from HT



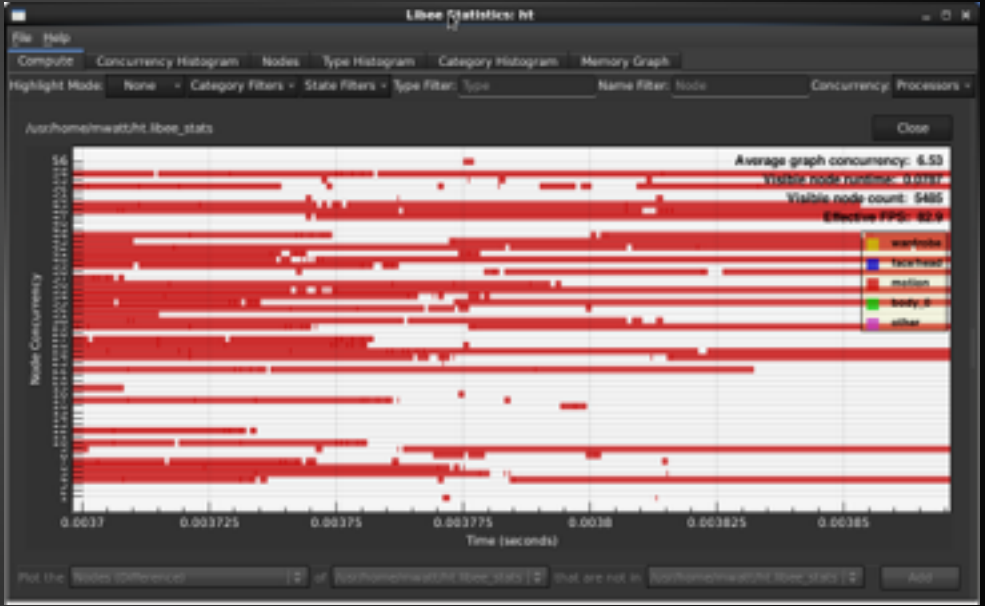
Hyperthreading: load balancing

More cores than work

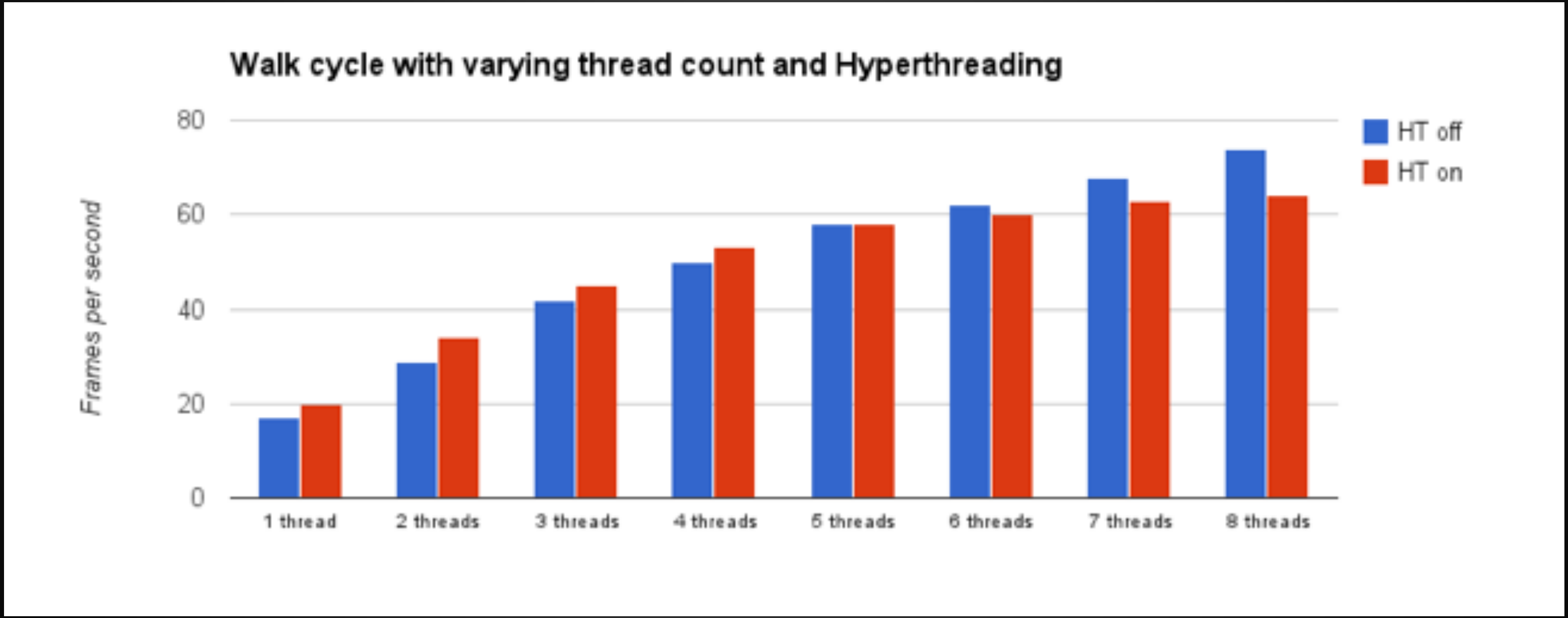
Two tasks can run on same core while other cores are idle

Hard to avoid as tasks come and go

Inefficient system usage



Hyperthreading vs workload



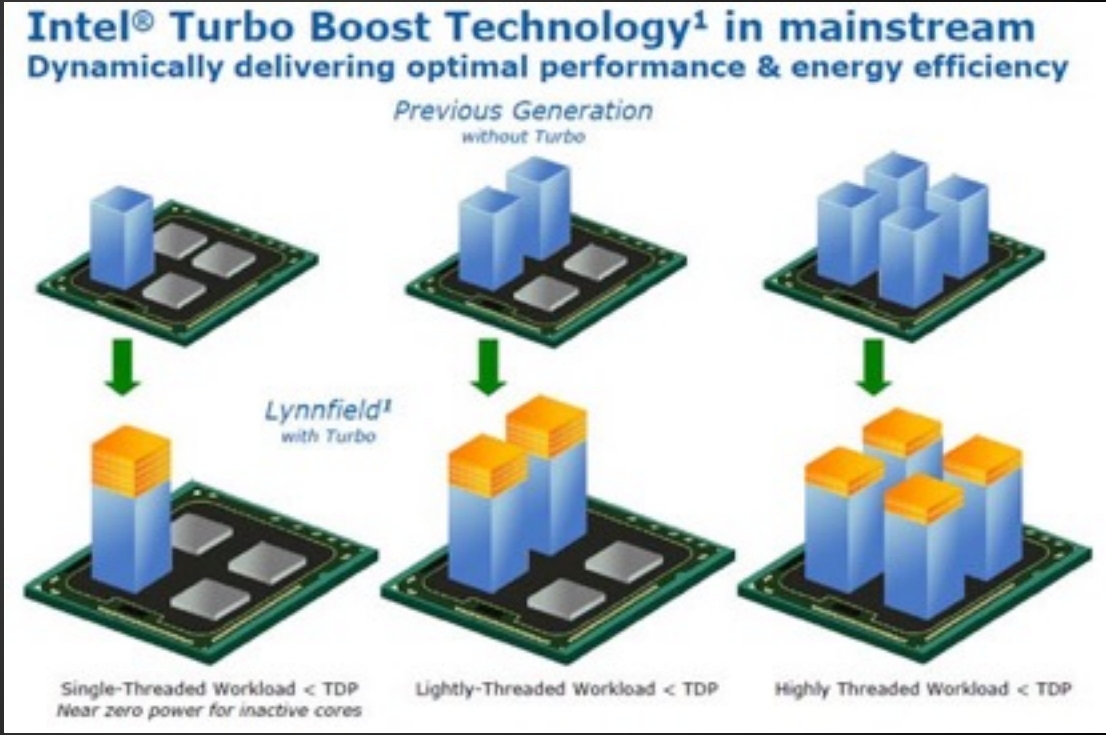
Turbo Boost

Fewer active cores

->

Faster clock speed

Careful when doing scalability tests



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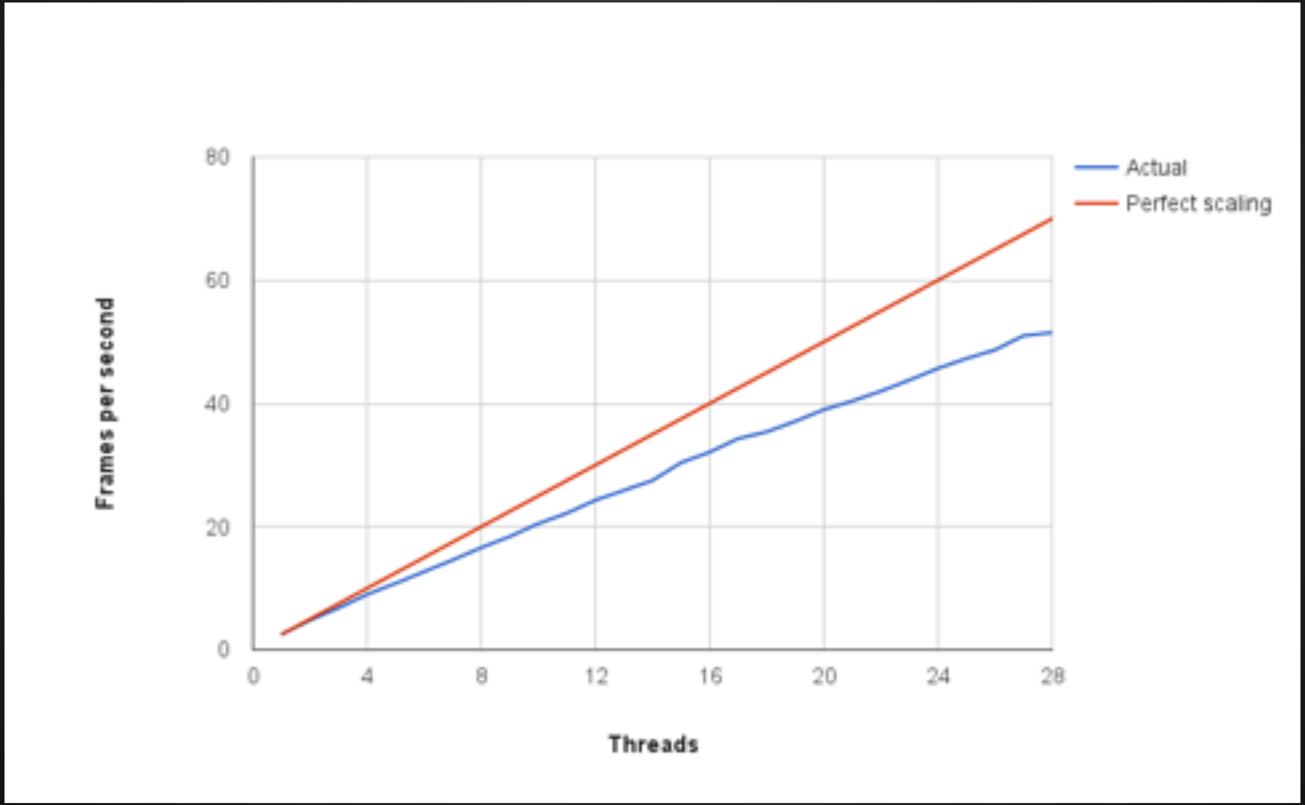
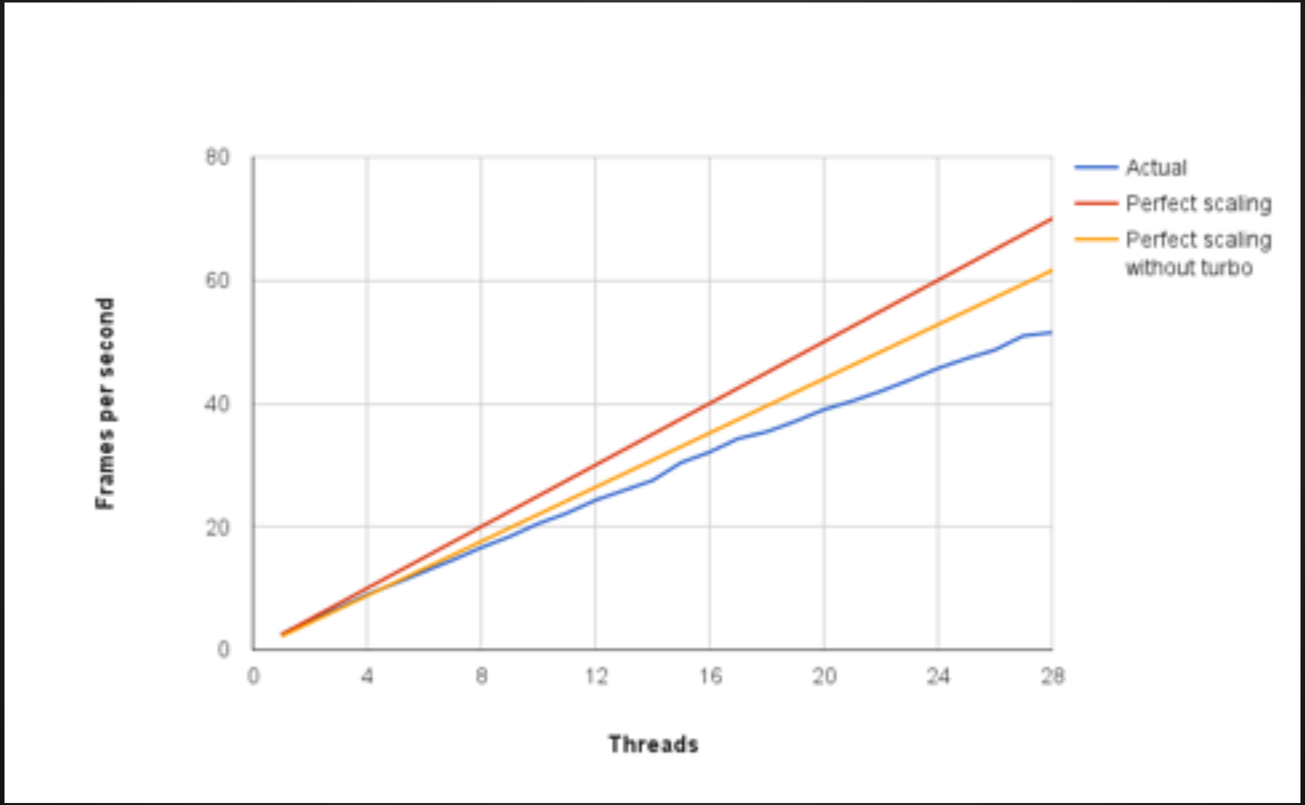
Apparent scaling: 75% of ideal



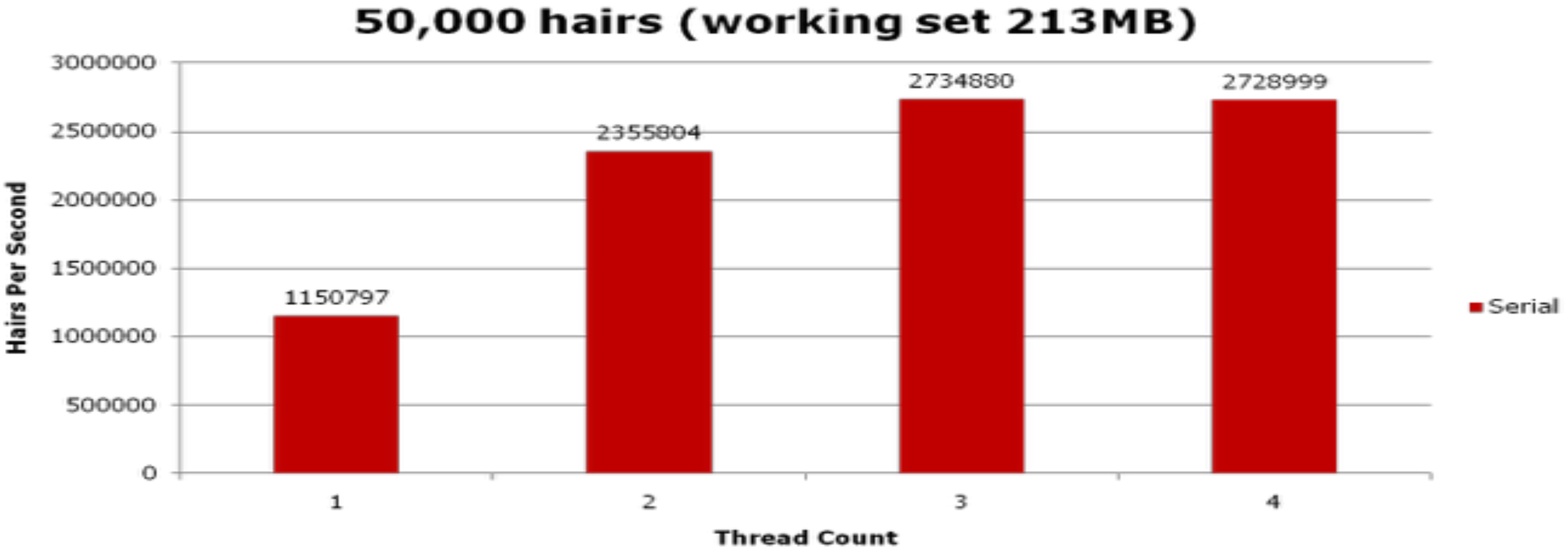
Real scaling: 85% of ideal



The memory wall

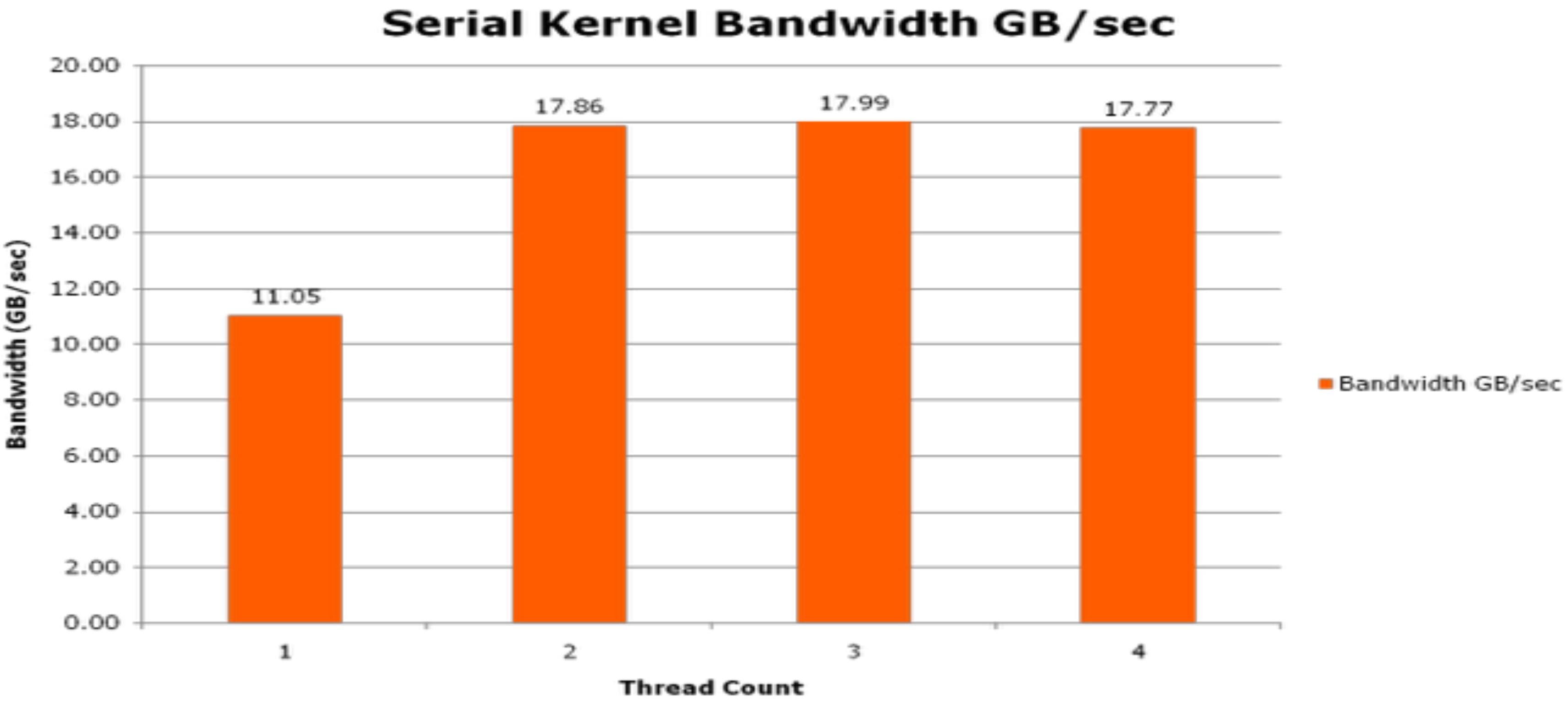
Example from DreamWorks hair system...

Threading Scalability



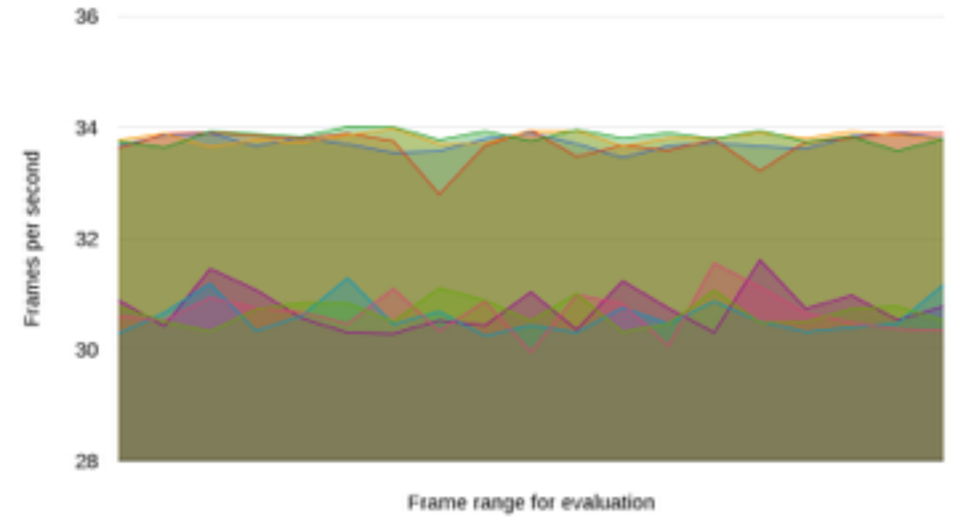
- Great scaling to 2 threads!
- Some brick wall hit for thread 3 and 4
- Looking at multiple runs, scalability peaks at 2.7x for 4 threads

Observed Bandwidth using SNB IMC events on 50K hairs (working set 213MB) Serial code



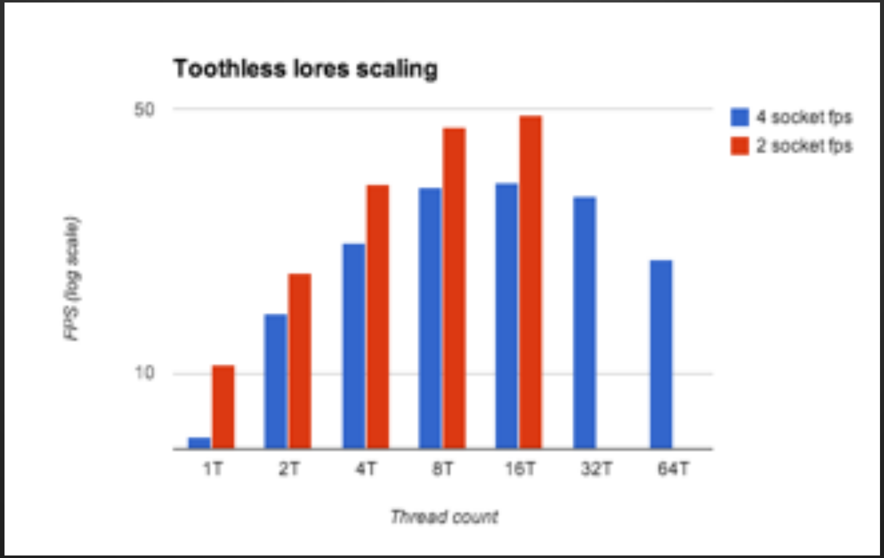
Thread affinity

Affinity faster, more consistent.
More important with more cores, NUMA

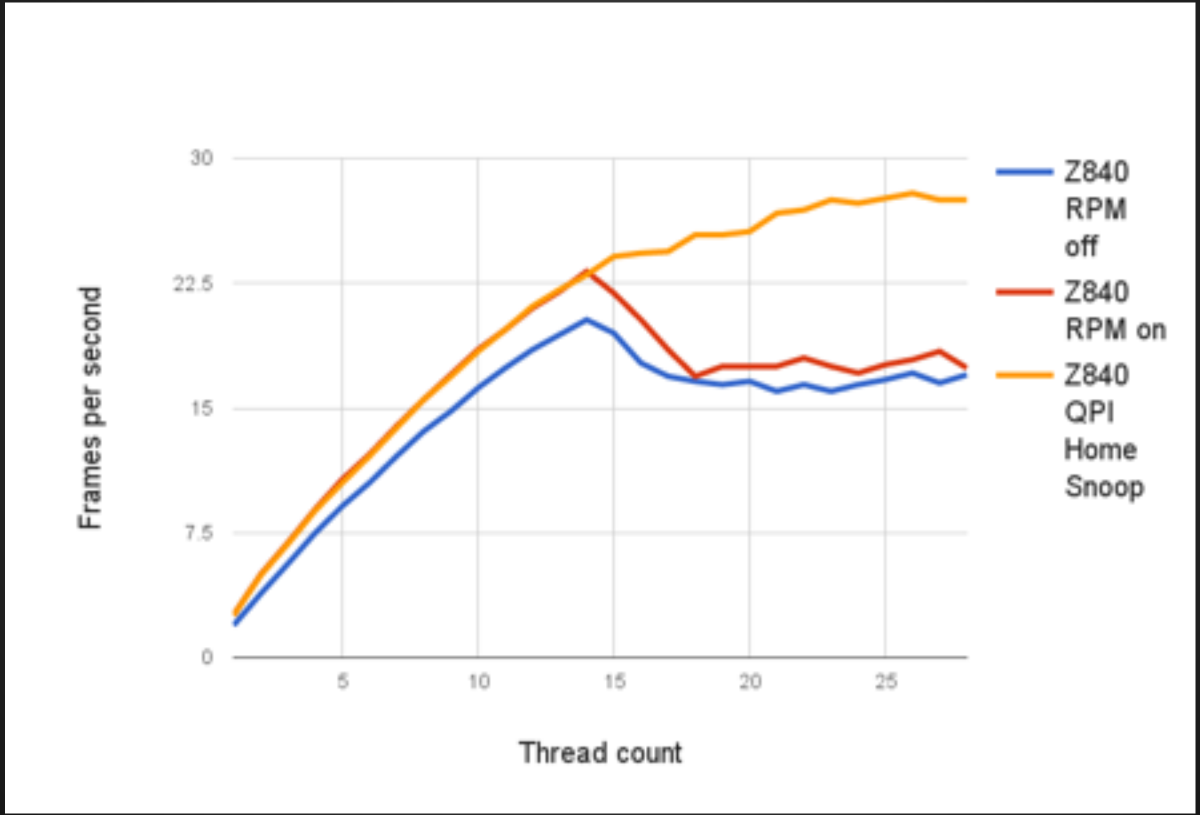


NUMA: 4 socket system

NUMA effects much more severe, taskset more critical
High thread count dropoff easier to hit



Dual socket Haswell



The villain: QPI snoop (!)

The QPI Snoop Configuration setting will control how cache snoops are handled.

When using the “Early Snoop” option the snoops will be sent by the caching agents; this will provide better cache latency for processors when the snoop traffic is low.

The “Home Snoop” option will cause the snoops to be sent from the home agent; this provides optimal memory bandwidth balanced across local and remote memory access.

Moral

Need to check machine configurations carefully

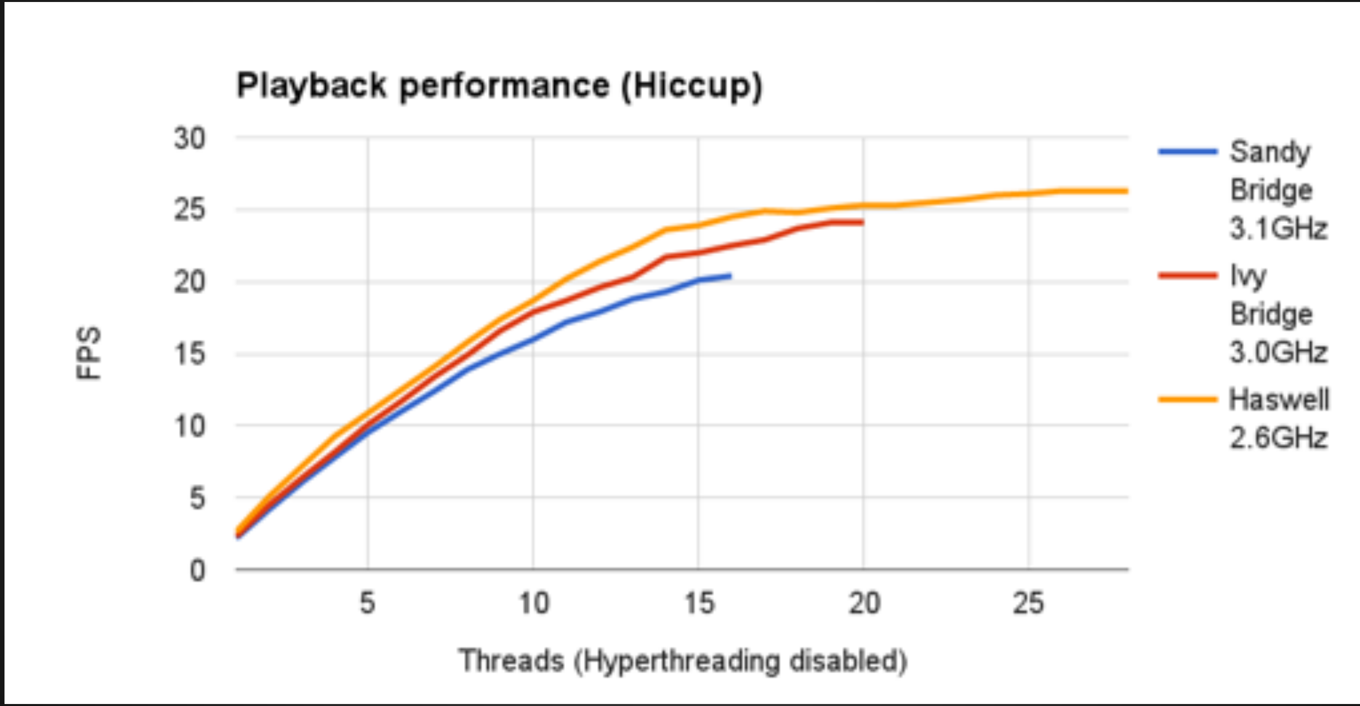
Things keep getting more complicated

More variables to optimize within power constraints

Don’t assume BIOS is set up optimally for your needs

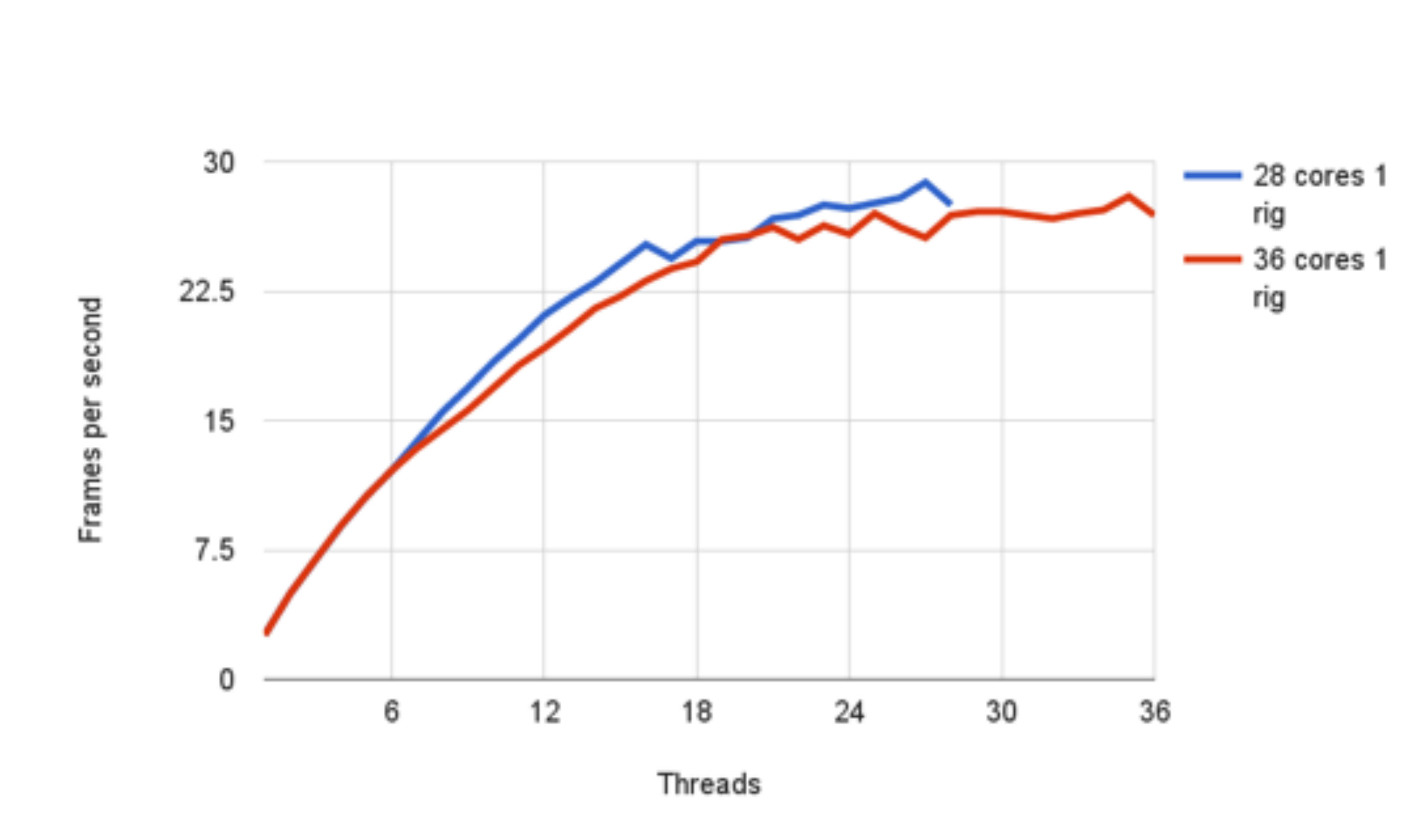
Limits of scalability

Performance with newer CPUs

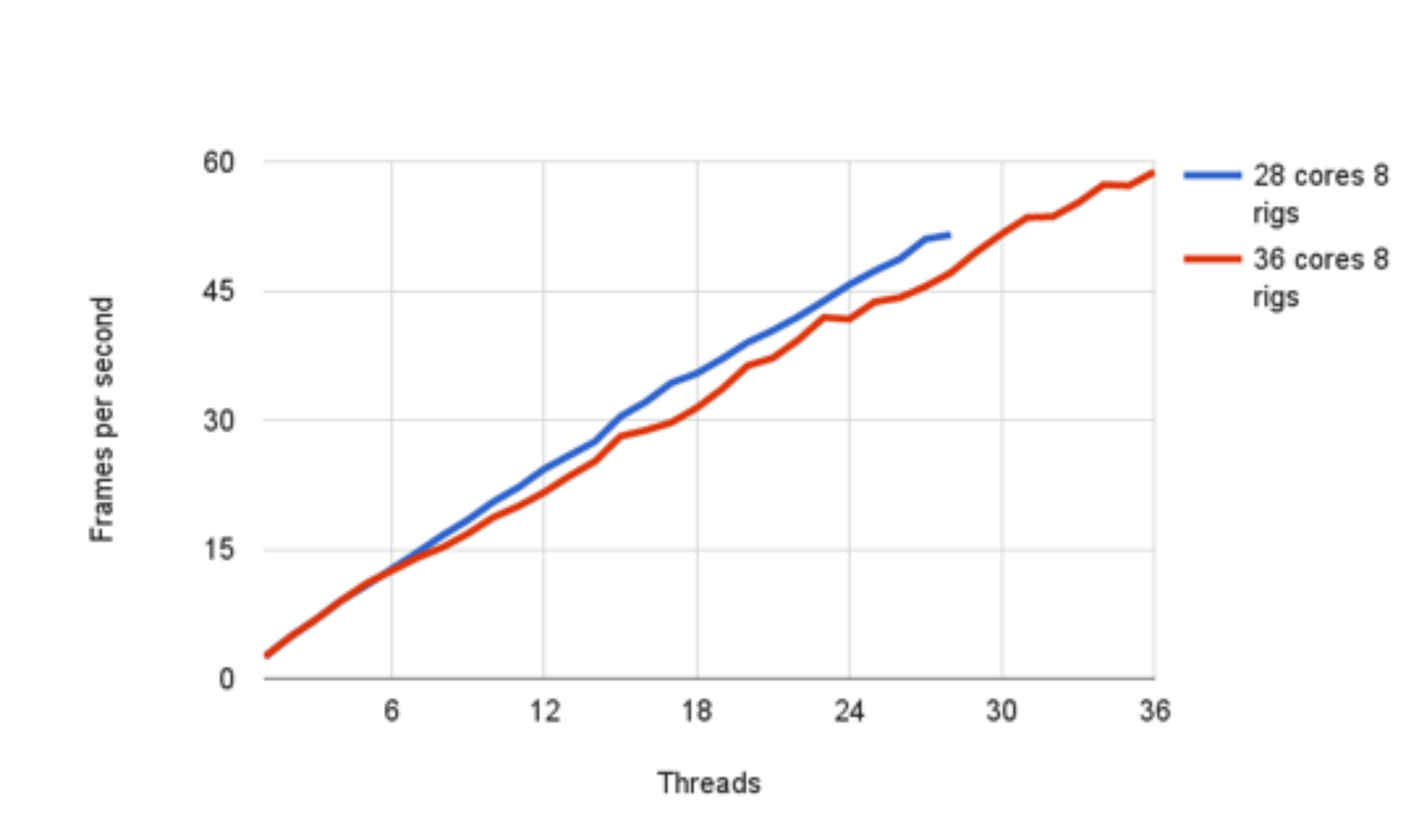


More cores (16->20->28). Lower clock (3.1->3.0->2.6GHz)

Haswell 28 vs 36 cores, 1 rig



Haswell 28 vs 36 cores, 8 rigs



Haswell 28 vs 36 cores

Do you take 10% more clock or 20% more cores?

Depends on workload scalability

Other Siggraph 2015 presentations

XBB (Transform Building Blocks)
http://www.slideshare.net/IntelSoftware/dreamworks-animation-51882186

SBB (SIMD Building Blocks)
http://www.slideshare.net/IntelSoftware/dreamwork-animation-dwa

THANKS!

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“Multithreading for Visual Effects”