ILP Ends TLP Begins

Today's topics:

Explore a perfect machine

unlimited budget to see where ILP goes

answer: not far enough

Look to TLP & multi-threading for help

everything has it's issues

we'll look at some of them

Apology

a bit more data than usual

try not to yawn LOUDLY

ILP Limits via an Oracle

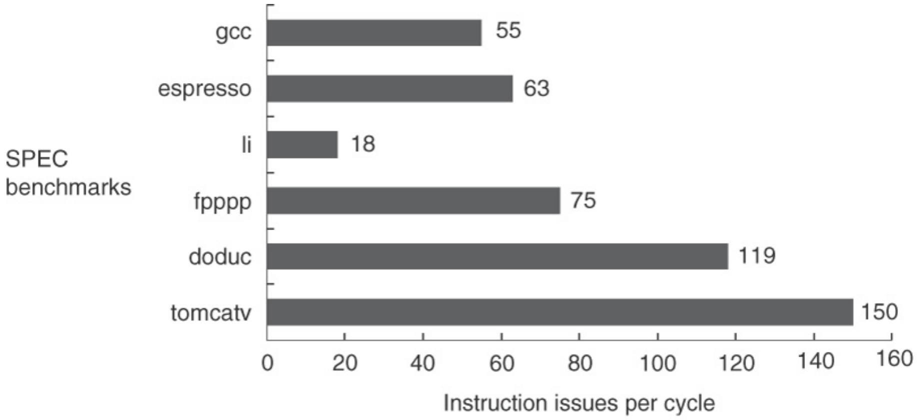
- Suspend reality and think of a perfect machine
  - infinite number of rename registers
    - » no Wax hazards
    - » for window size of n: n^2-n comparisons for each register field
  - perfect branch & jump prediction
    - » unbounded buffer of instructions available for execution
  - perfect address alias analysis
    - » independent loads can be moved ahead of stores
  - perfect L1$'s
    - » hit in 1 cycle
  - as many XU's as will ever be needed
    - » no structural stalls
- Infinite cost unrealistic
  - simulate rather than build
    - » allows exploration
      - just how far can we get with ILP on a perfect machine
      - and sequential code

IBM Power5

- **Most advanced superscalar processor to date**
  - **4 fetch**
  - **6 issue**
  - **88 integer rename regs, 88 float rename regs**
  - **pipeline has over 200 instructions in flight**
    - » **including 32 loads and 32 stores**
- **Not quite the Oracle but on the way**
  - **consumes a lot of power**
  - **target is blade server segment**

ILP w/ Infinite Window Size

- **Looks great**
  - **when compared w/ today's IPC < 3**
    - » **if you can ignore the infinite cost**



Limit Window Size

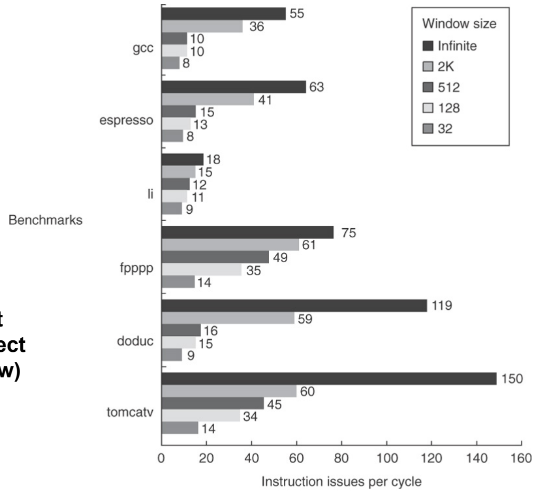
- **ILP shrinks rapidly**

2K = ~ 4M * 3 5-bit compares
512 = 785K compares
128 = 49K compares
32 = 3K compares

Plus compares happen every cycle

conclude 32 is doable but watty

can improve by maybe 3x at great cost (remember this is still a perfect machine – just w/ a limited window)



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Switch to Half-Infinity

- **You do the math**
- **For the remaining data assume**
  - **2K window size**
    - » **~12 M 5-bit compares every clock**
    - » **>10x bigger than anything that's been built**
  - **64 issue**
    - » **~10x more than anything real**
- **Why choose this**
  - **given other restrictions it won't be a limit**
    - » **can you say "easier to simulate"**
    - » **I knew you could**

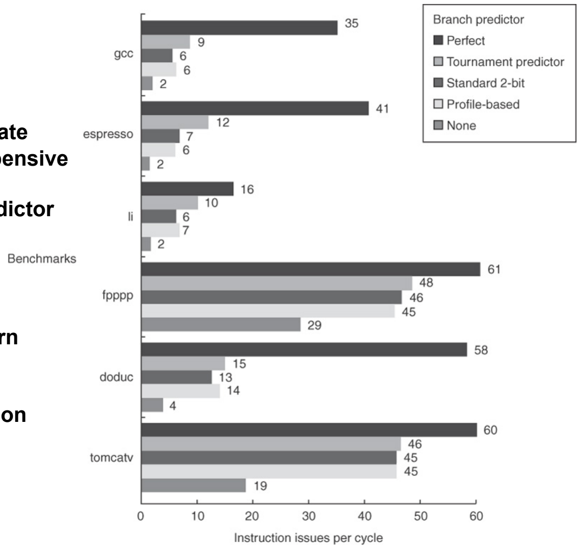
Look at Semi-Real Branch Prediction

Tnmt: 8K entry predictor
Jump predictor: 2K entries
48K bits and 3% mispredict rate
which is very good – just expensive

Standard: 512 entry 2-bit predictor

Conclusion:
have to predict
integer codes are a problem
yet highly important in modern
data-center apps

Nobody makes much money on
floating point – sad reality



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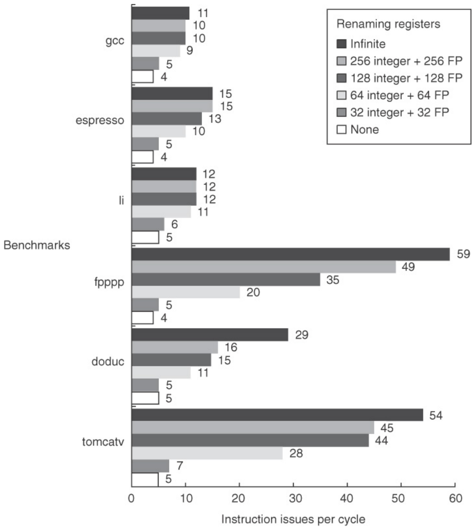
Limiting Rename Registers

Integer codes remain problematic

$ problem with FP remains but ILP
looks good if you don't care about $

conclusion – need around 64 renamed
registers to make much of a difference



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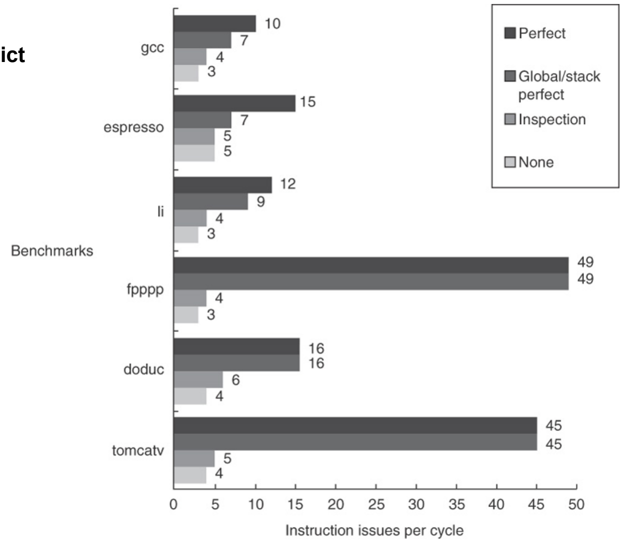
Alias Analysis Influence

GL/STK – heap ref's conflict but nothing else

Inspection – what can the compiler do?



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Ambitious but Possible?

- HAL
  - 1 better than IBM in all letters
  - 64 issue no restrictions
    - » this one is actually ridiculous
      - it does focus on ILP limits rather than structural stalls
  - 1K entry tournament predictor
    - » this has been done
  - perfect disambiguation
    - » note close to possible for small window sizes
    - » impractical for large windows
  - 64 register rename pool
    - » ~100 have been done
- What do we get?
  - Al the Harpy says "a really good heater"

And VIOLA!

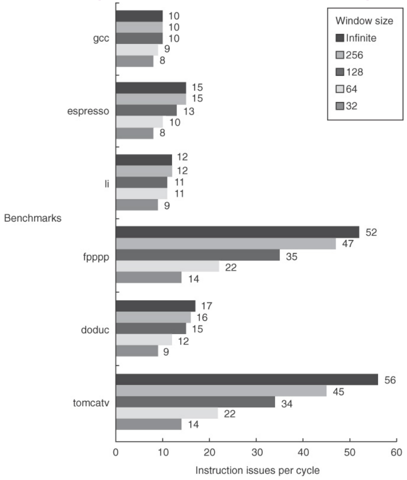
- **3-4x improvement**
  - **for a machine nobody will buy – too hot, too costly**

Interesting study & clear conclusion:

ILP is already past the point of diminishing return

Programmer is going to need to help out w/ exposing parallelism

Need a different type of HW support for parallelism



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Enter TLP

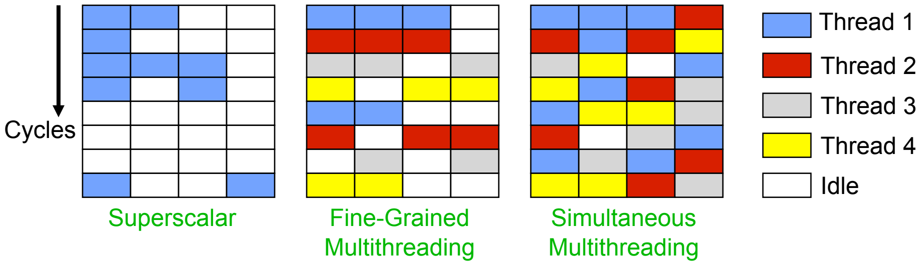
- **Again not a new idea**
  - **been around for > 10 years**
    - » **Tullsen – UW – 1995 publishes the SMT idea**
    - » **TERA MTA & IBM Pulsar show up in late 90's – both MT**
- **Thread vs. Process confusion**
  - **process runs in it's own virtual memory space**
    - » **no shared memory**
    - » **lots of OS protection & overhead**
    - » **communicate via "message like channels" – e.g. pipes in Unix**
  - **threads**
    - » **share memory and therefore synchronization needed**
  - **both are independent entities**
    - » **with their own sets of registers and process state**
  - **TLP difference**
    - » **multiple threads can run concurrently or interleaved on the same processor**
    - » **one at a time and context switch for processes**

Multi-Threading

- **2 variants**
  - **fine-grained MT – e.g. TERA**
    - » round robin walk through threads
      - next cycle – next thread
    - » TERA – 128 threads
      - built in 128 cycle load-use delay
        - – basic idea was to cover main memory latency and do away w/ caches
        - – great if you put every app into a 128 thread mold
      - it failed and Burton goes to the dark side (a.k.a. Microsoft)
  - **coarse grained MT – e.g. IBM Pulsar**
    - » sometimes called “switch on miss”
    - » basic idea
      - anytime something bad happens
        - – TLB or L2 miss
      - switch to next runable thread
        - – some sort of fairness policy is required
        - – usually just round-robin suffices
      - similar goal – hide performance effect of long stalls

Symmetric Multithreading

- **Idea**
  - **multiple independent threads**
  - **increase number of parallel instructions to issue**

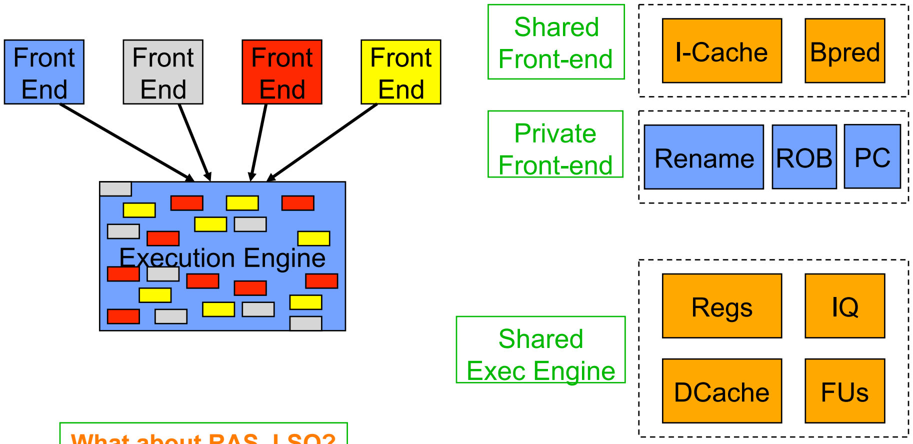


- » superscalar – not enough ILP and idle on cache miss
- » FGMT – not enough ILP in any one thread
- » SMT – improves since broader set of independent instructions
  - programmer supplied parallelism
  - takes advantage of dynamic issue superscalar tactics

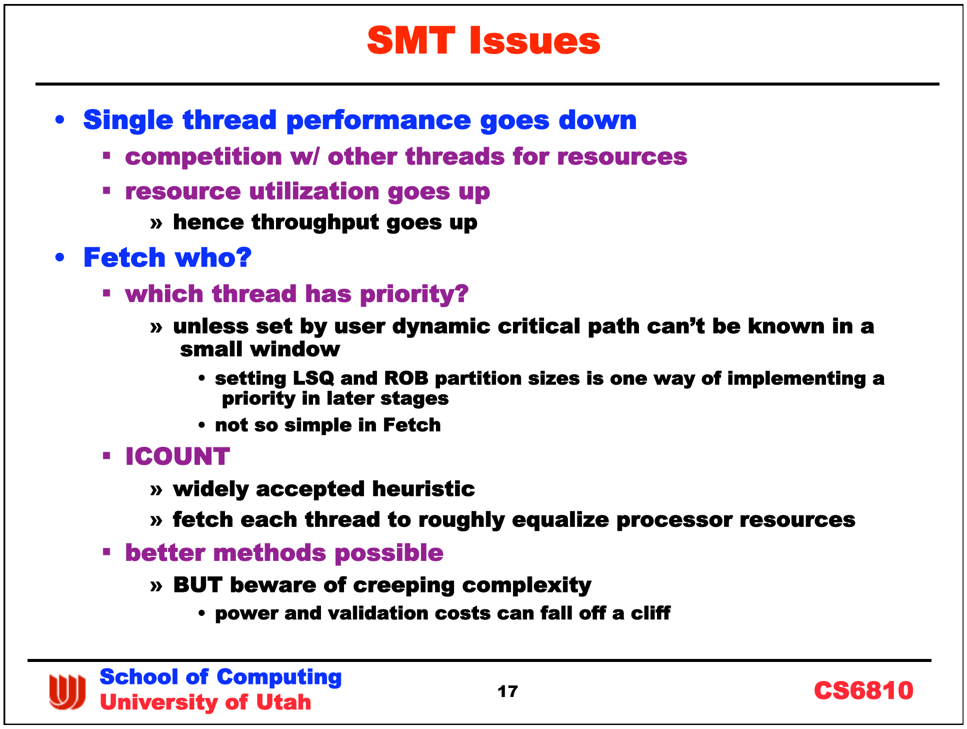
SMT Resource Perspective

- **Each thread has it's own**
  - **PC, next PC**
    - » **next is needed for exceptions**
  - **private logical registers**
    - » **and mapping to renamed physical registers**
  - **ROB**
    - » **if shared a stall in one thread will stall the others**
- **Shared**
  - **branch predictor**
    - » **larger size will be needed**
  - **main memory ports, TLB, page table**
    - » **artifact of shared memory**
    - » **more threads does increase memory pressure**
      - **biggest problem is single ported L1$'s**

SMT Pipeline Structure

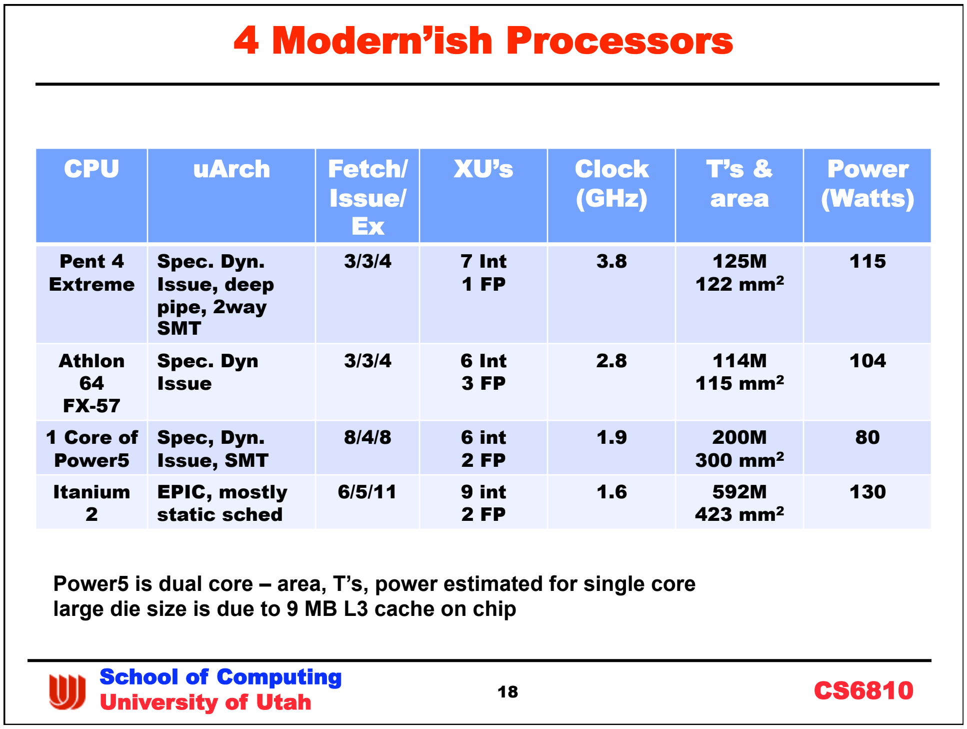


What about RAS, LSQ?



SMT Issues

- Single thread performance goes down
  - competition w/ other threads for resources
  - resource utilization goes up
    - » hence throughput goes up
- Fetch who?
  - which thread has priority?
    - » unless set by user dynamic critical path can't be known in a small window
      - setting LSQ and ROB partition sizes is one way of implementing a priority in later stages
      - not so simple in Fetch
  - ICOUNT
    - » widely accepted heuristic
    - » fetch each thread to roughly equalize processor resources
  - better methods possible
    - » BUT beware of creeping complexity
      - power and validation costs can fall off a cliff

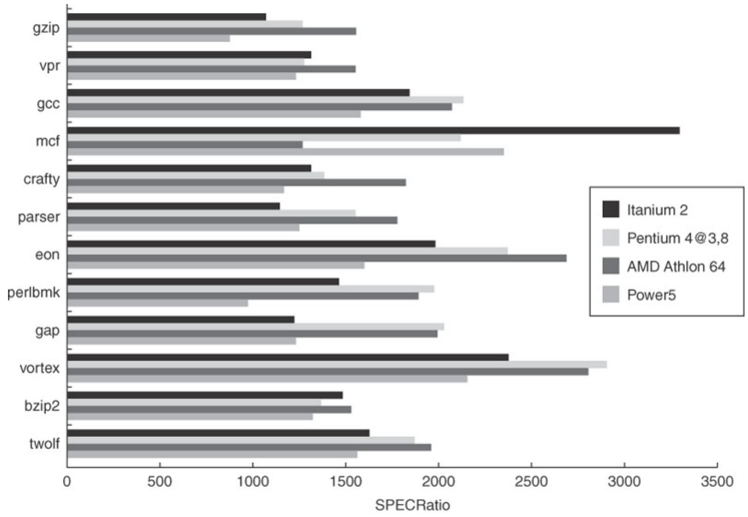


4 Modern'ish Processors

CPU	uArch	Fetch/ Issue/ Ex	XU's	Clock (GHz)	T's & area	Power (Watts)
Pent 4 Extreme	Spec. Dyn. Issue, deep pipe, 2way SMT	3/3/4	7 Int 1 FP	3.8	125M 122 mm^2	115
Athlon 64 FX-57	Spec. Dyn Issue	3/3/4	6 Int 3 FP	2.8	114M 115 mm^2	104
1 Core of Power5	Spec, Dyn. Issue, SMT	8/4/8	6 int 2 FP	1.9	200M 300 mm^2	80
Itanium 2	EPIC, mostly static sched	6/5/11	9 int 2 FP	1.6	592M 423 mm^2	130

Power5 is dual core – area, T's, power estimated for single core
large die size is due to 9 MB L3 cache on chip

SPECint2000



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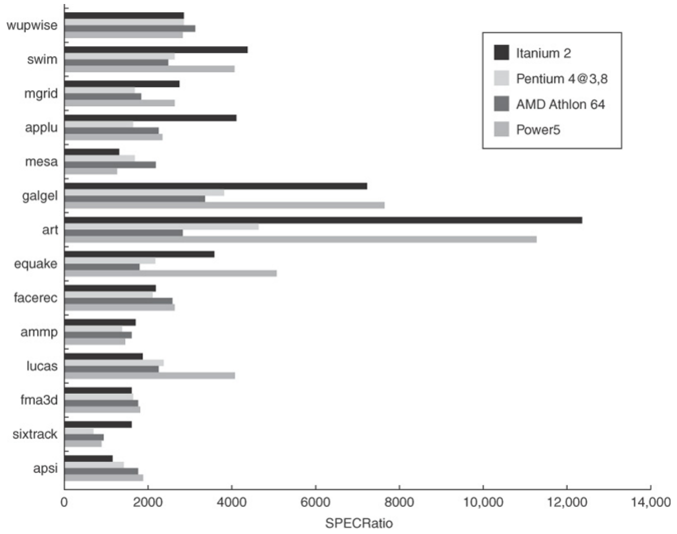
SPECfp2000



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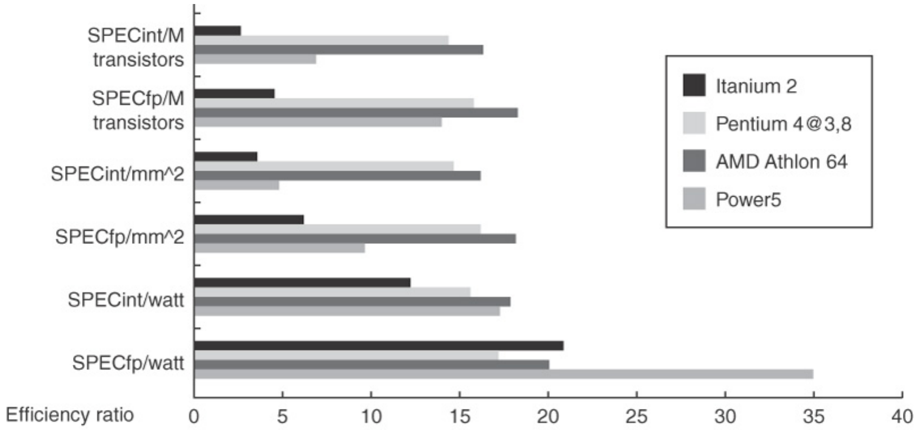
Efficiency



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Note: as we move into multi-core perf/watt becomes the critical efficiency metric
Even better: energy-delay product since that is architecture and workload specific

Concluding Remarks

- **SMT is a big boost to the ILP game**
  - **uses previous skills in dynamic superscalar architecture**
  - **rules of thumb**
    - » **double threads**
      - **1.6x performance gain**
      - **~10-15% power gain**
  - **where does the curve saturate**
    - » **depends on workload**
      - **~4/core seems to be a sweet spot**
      - **time will tell**
    - » **Sun Niagra Falls**
      - **8 cores, 8 threads/core**
        - – **simpler cores however**
      - **performs well in the data-center**
- **Next**
  - **leave processor side and examine the memory side**
    - » **both need to be balanced and done right to win**