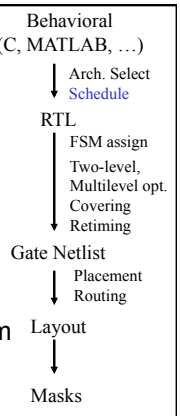
ESE535: Electronic Design Automation

Day 5: January 31, 2011
Scheduling
Variants and Approaches

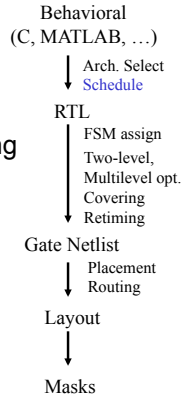
Previously

- Resources aren't free
- Share to reduce costs
- Schedule operations on resources
  - Fixed resources
- Greedy approximation algorithm
- List Scheduling for resource-constrained scheduling



Today

- Time-Constrained Scheduling
  - Force Directed
- Few words on project architecture
- Resource-Constrained
  - Branch-and-Bound



Force Directed

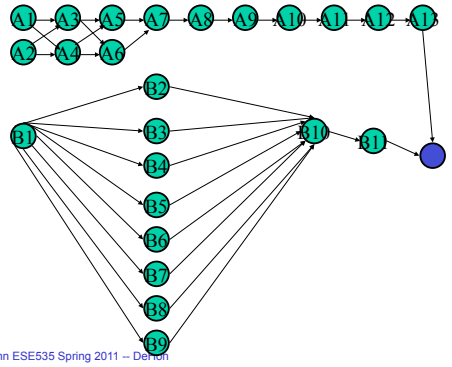
Force-Directed

- **Problem**: how exploit schedule freedom (slack) to minimize instantaneous resources
  - Directly solve time-constrained scheduling
    - (previously only solved indirectly)
  - Minimize resources with timing target

Force-Directed

- Given a node, can schedule anywhere between ASAP and ALAP schedule time
  - Between latest schedule predecessor and ALAP
  - Between ASAP and already scheduled successors
  - Between latest schedule predecessor and earliest schedule successor
- *That is:* Scheduling node will limit freedom of nodes in path

Single Resource Challenge



Force-Directed

- If everything where scheduled, **except** for the target node, what would we do?:
  - examine resource usage in all timeslots allowed by precedence
  - place in timeslot which has least increase maximum resources
    - Least energy
    - Where the forces are pulling it

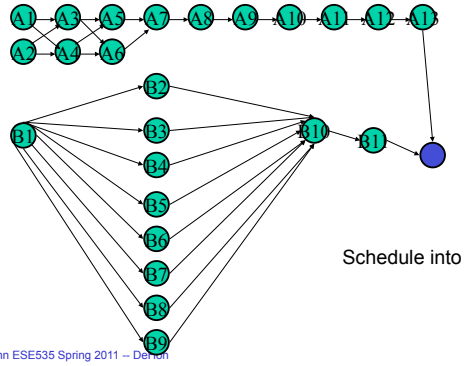
Force-Directed

- **Problem:** don't know resource utilization during scheduling
- **Strategy:** estimate resource utilization

Force-Directed Estimate

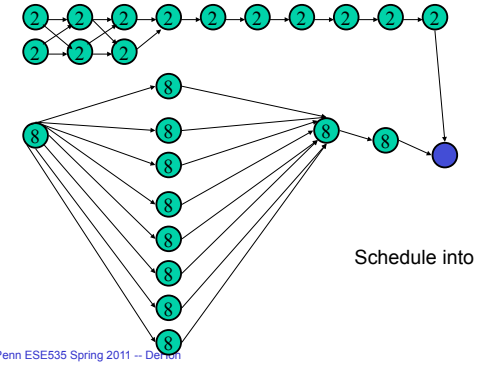
- Assume a node is uniformly distributed within slack region
  - between earliest and latest possible schedule time
- Use this estimate to identify most used timeslots

Single Resource Challenge



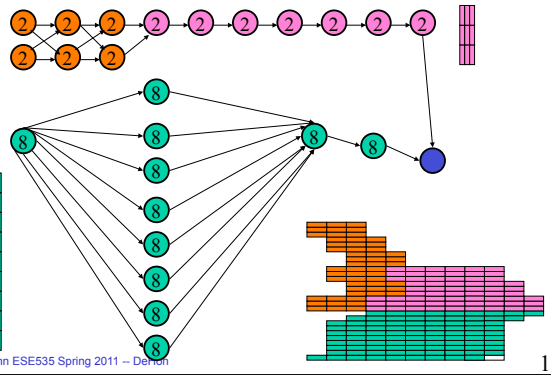
Schedule into 12 cycles

Slacks on all nodes

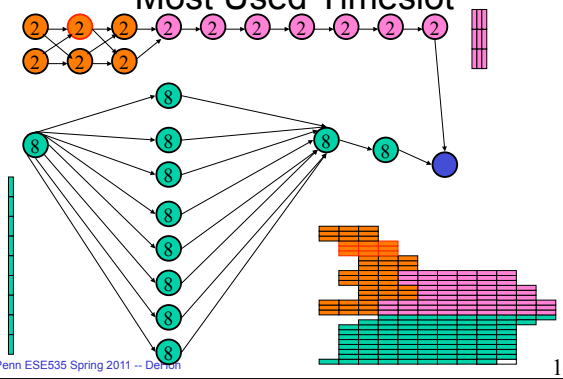


Schedule into 12 cycles

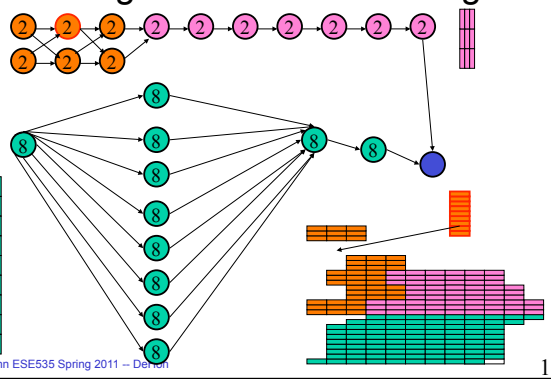
Uniform Distribution of Slack



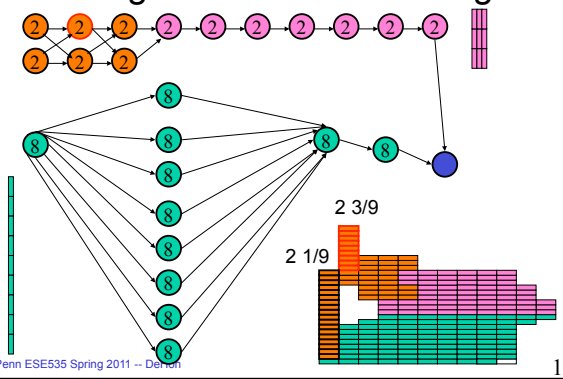
Most Constrained Node, Most Used Timeslot



Single Resource Challenge



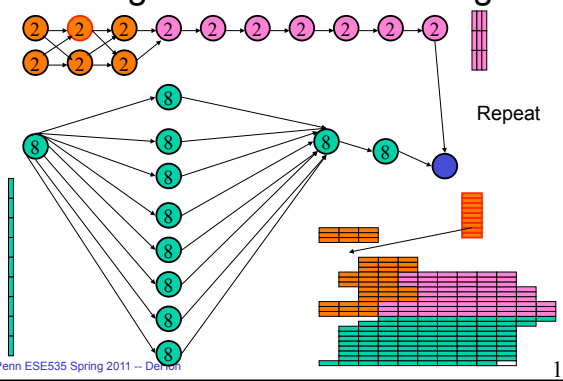
Single Resource Challenge

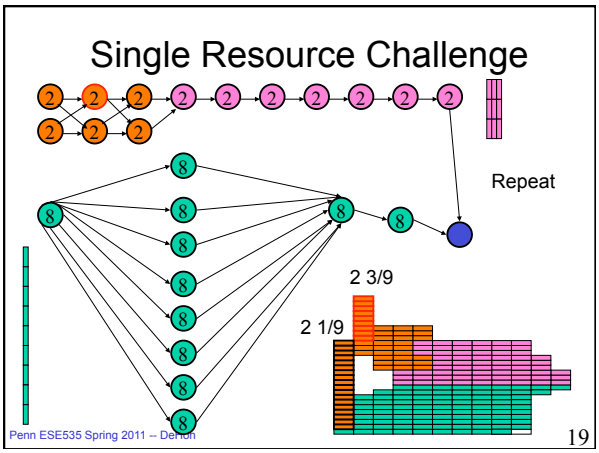


Force-Directed

- Scheduling a node will shift distribution
  - all of scheduled node's cost goes into one timeslot
  - predecessor/successors may have freedom limited so shift their contributions
- **Goal:** shift distribution to minimize maximum resource utilization (estimate)

Single Resource Challenge




Single Resource Challenge
Repeat
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2 1/9
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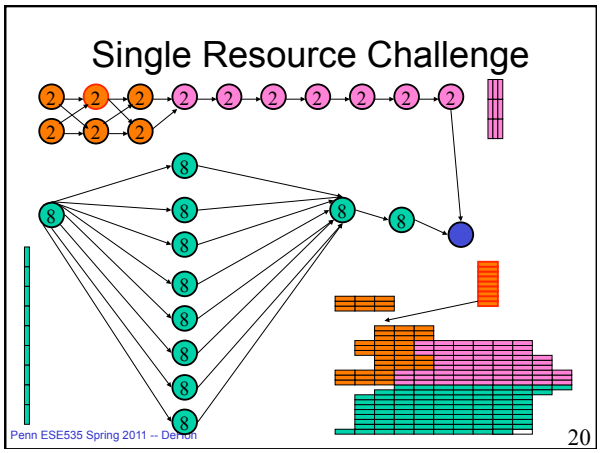
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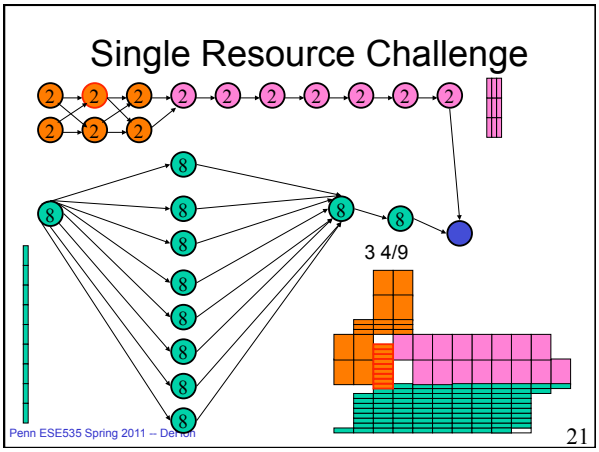
Single Resource Challenge
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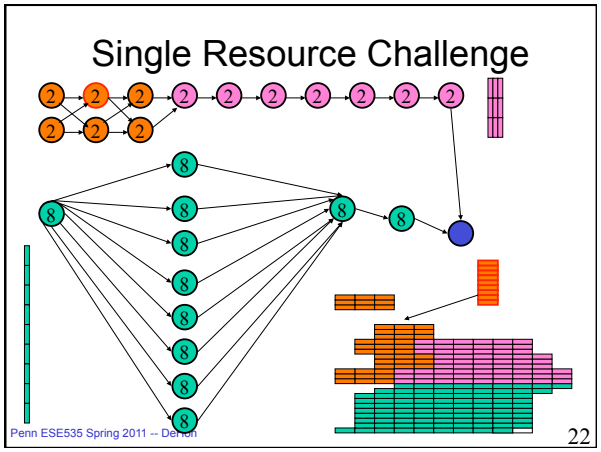
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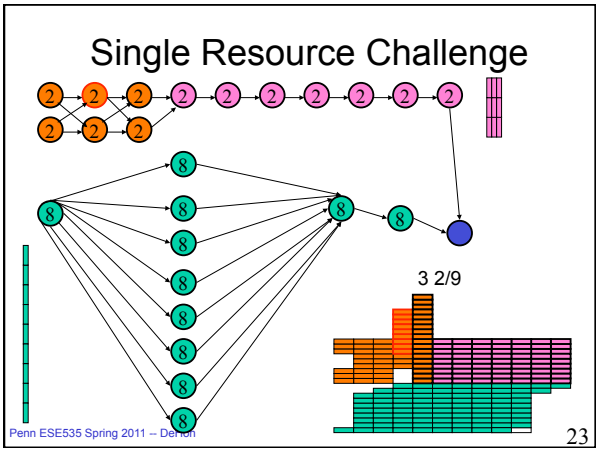
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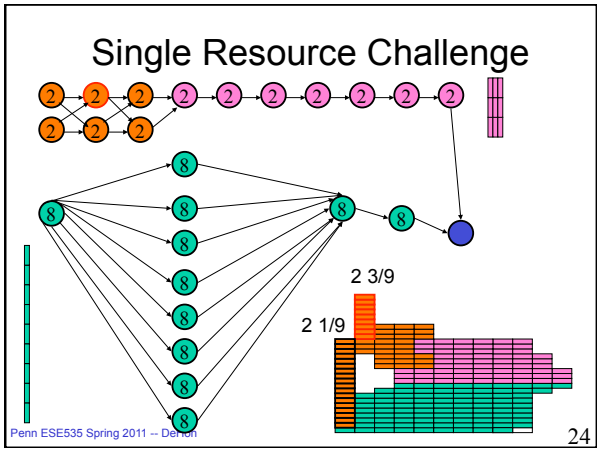
Single Resource Challenge
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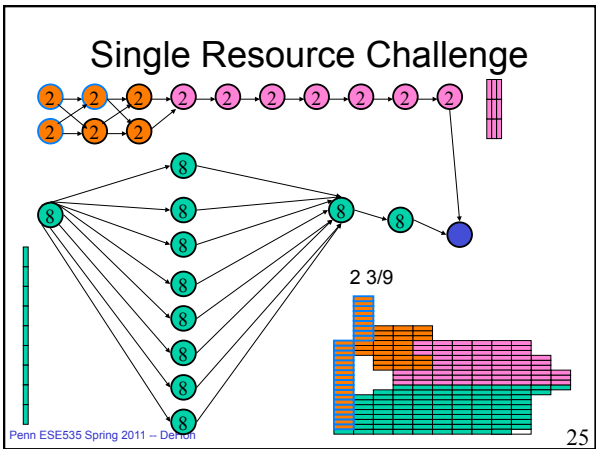
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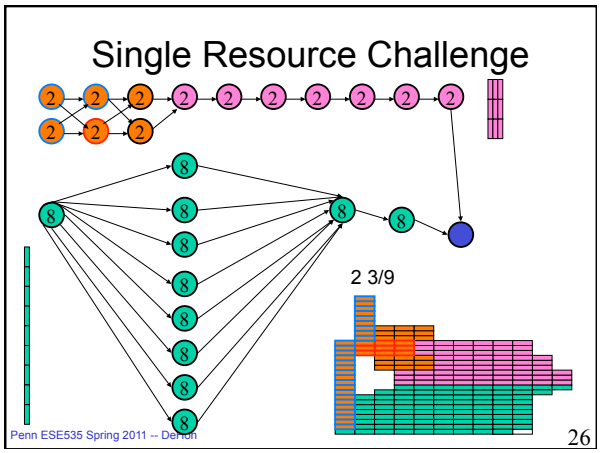
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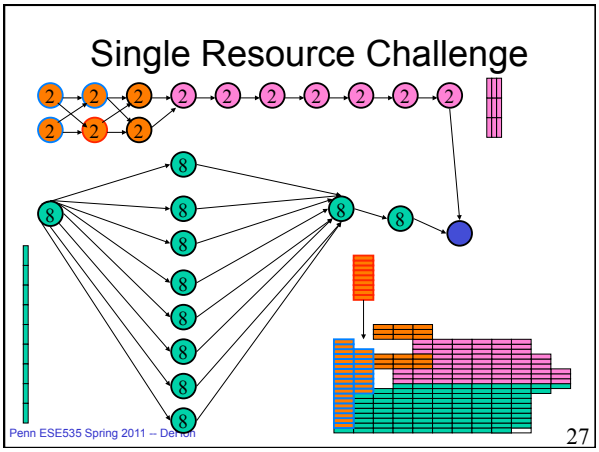
Single Resource Challenge
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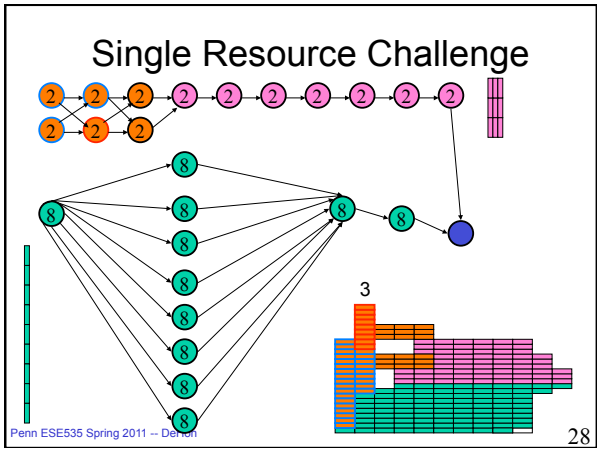
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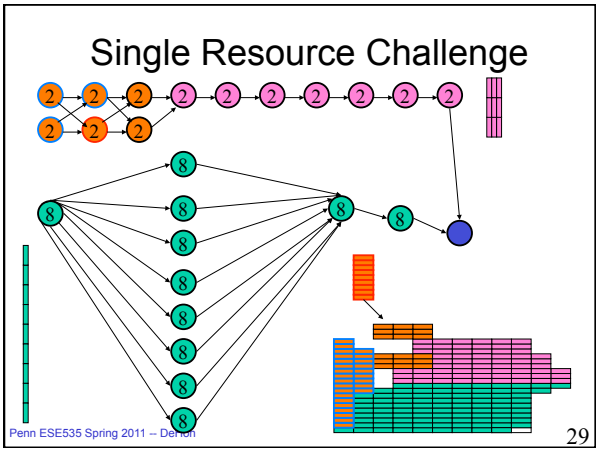
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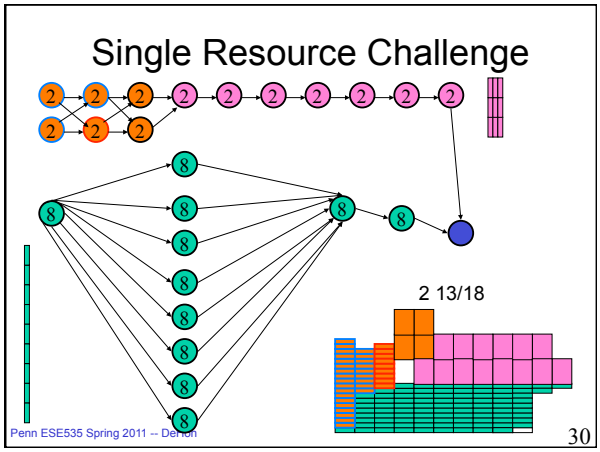
Single Resource Challenge
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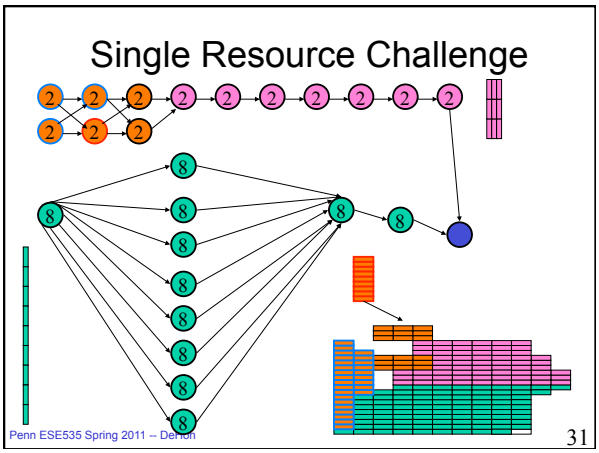
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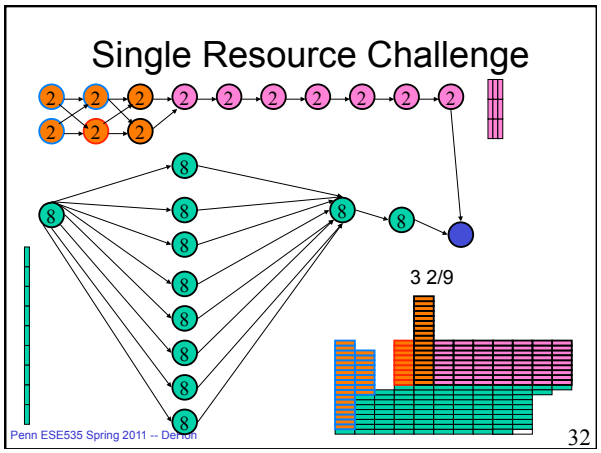
Single Resource Challenge
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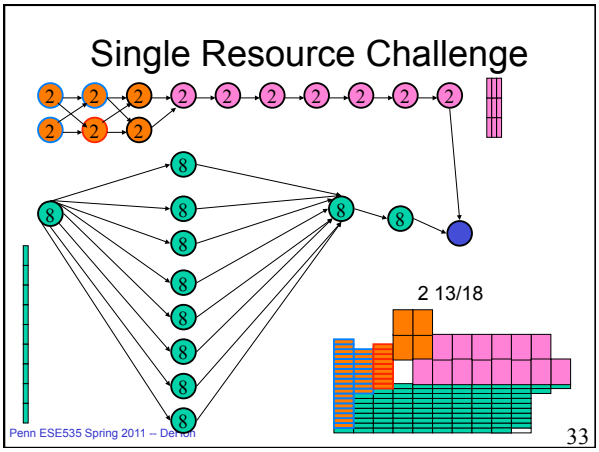
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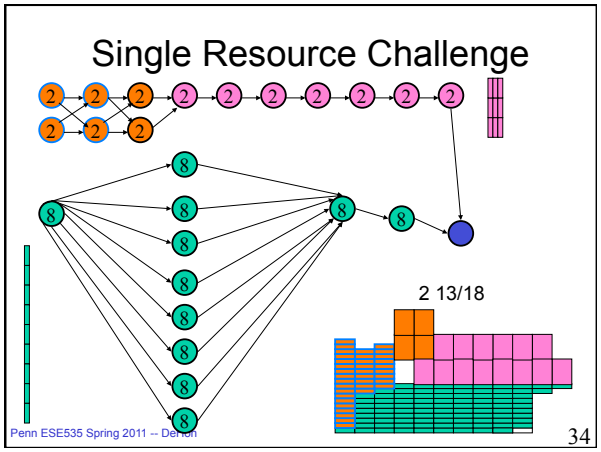
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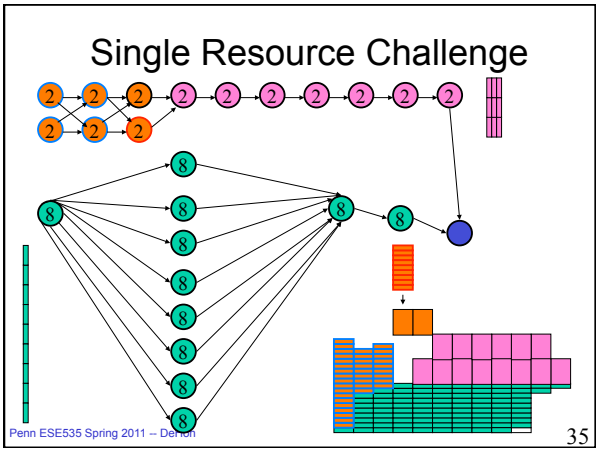
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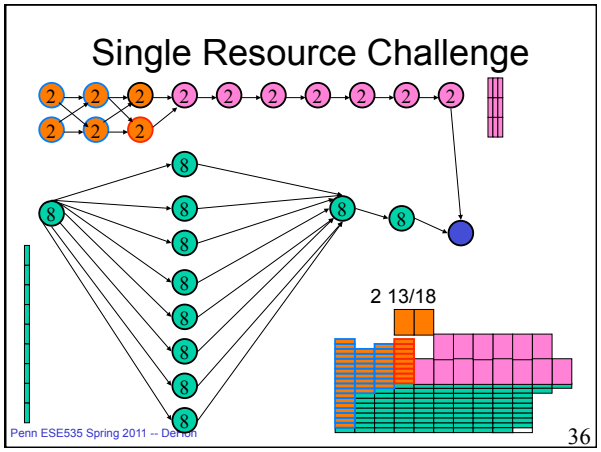
Single Resource Challenge
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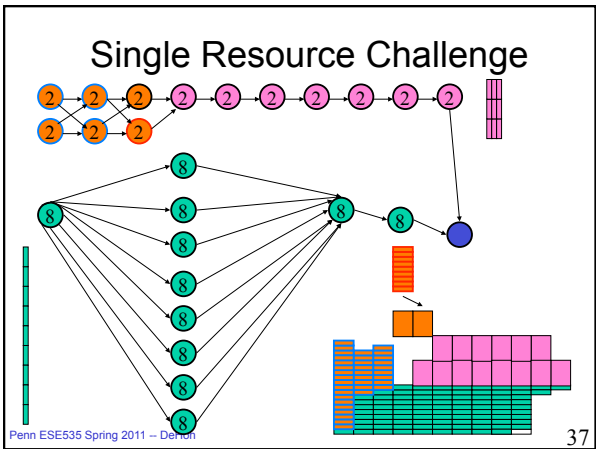
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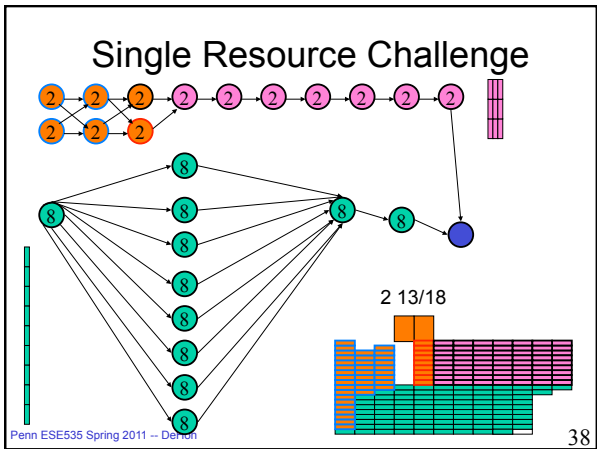
Single Resource Challenge
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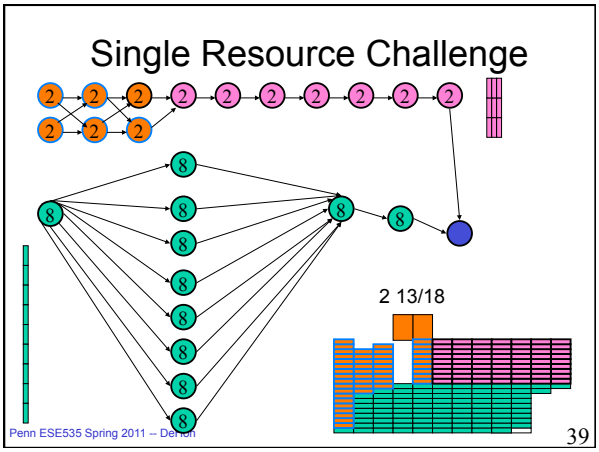
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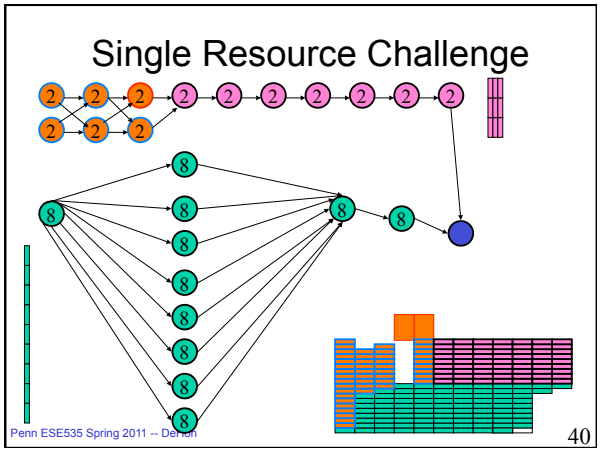
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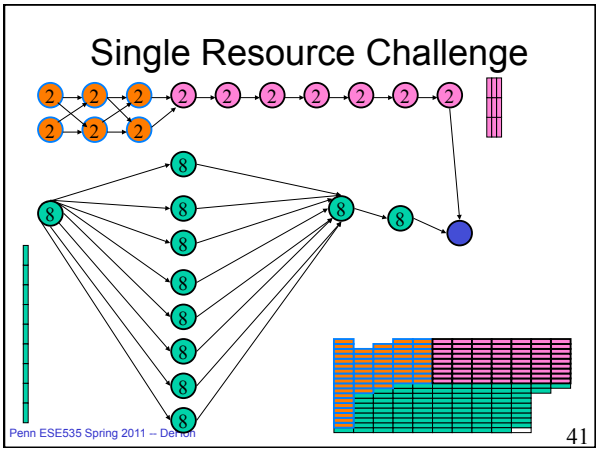
Single Resource Challenge
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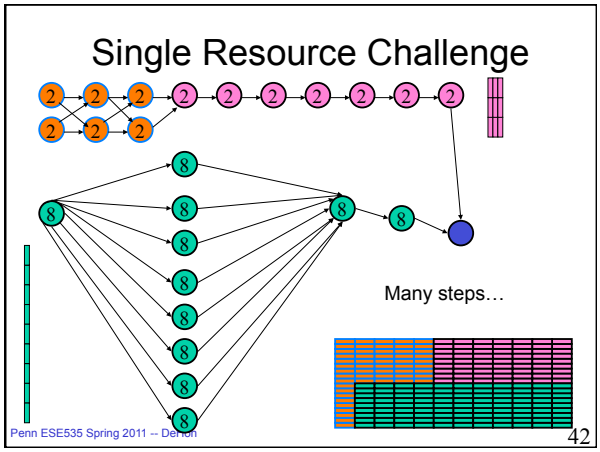
Single Resource Challenge
Many steps…
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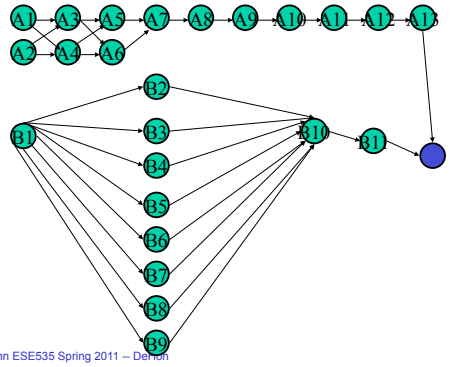
Single Resource Hard (5)



???
A1 B1
A2 B2
A3 A4
A5 B3
A6 B4
A7 B5
A8 B6
A9 B7
A10 B8
A11 B9
A12 B10
A13 B11

Force-Directed Algorithm

1. ASAP/ALAP schedule to determine range of times for each node
2. Compute estimated resource usage
3. Pick most constrained node (in largest time slot…)
   - Evaluate effects of placing in feasible time slots (compute forces)
   - Place in minimum cost slot and update estimates
   - Repeat until done

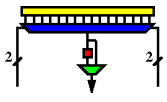
Force-Directed Runtime

- Evaluate force of putting in timeslot O(N)
  - Potentially perturbing slack on net prefix/ postfix for this node → N
- Each node potentially in T slots: ×T
- N nodes to place: ×N
- $O(N^2T)$
  - Loose bound--don't get both T slots and N perturbations

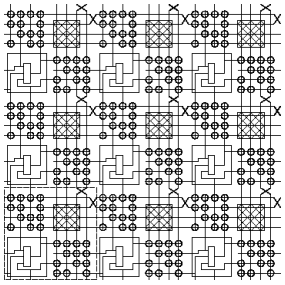
Project Architecture

FPGA

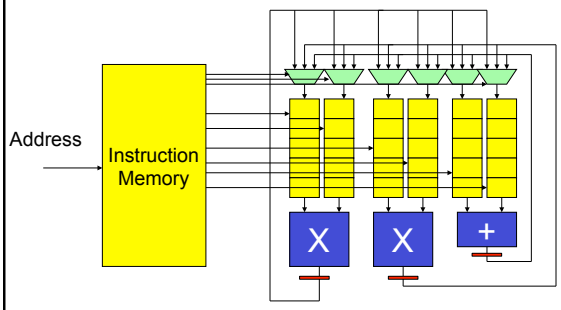
K-LUT (typical k=4)
Compute block
w/ optional
output Flip-Flop



ESE171, CIS371

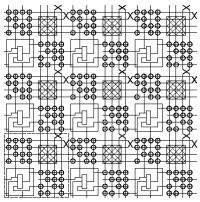


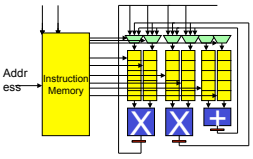
VLIW



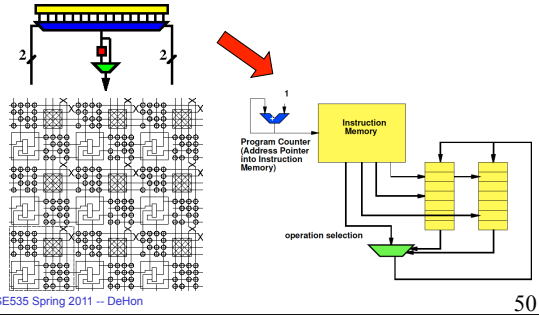
Merge Ideas

- Bit-level, LUT-based mesh
- VLIW, cycle-by-cycle control



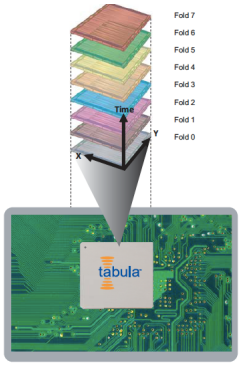


Time-Multiplexed LUT PE



Tabula

- March 1, 2010
  - Announced "new" architecture
- Bit-level, LUT-based VLIW with 8 instruction contexts



[src: www.tabula.com]

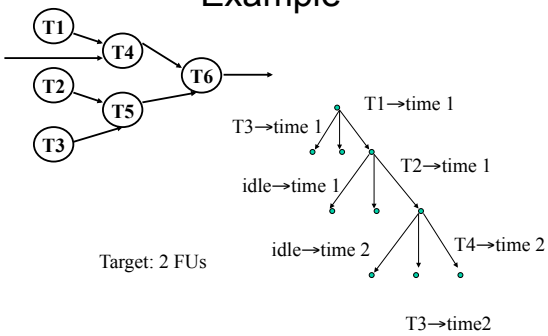
Branch-and-Bound

(for resource-constrained scheduling)

Brute-Force Scheduling (Exhaustive Search)

- Try all schedules
- Branching/Backtracking Search
- Start w/ nothing scheduled (ready queue)
- At each move (branch) pick:
  - available resource time slot
  - ready task (predecessors completed)
  - schedule task on resource
    - Update ready queue

Example



Branching Search

- Explores entire state space
  - finds optimum schedule
- Exponential work
  - O ($N^{(resources*time\text{-}slots)}$)
- Many schedules completely uninteresting

Reducing Work

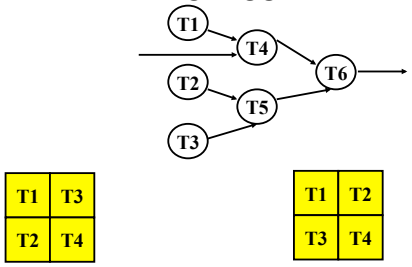
1. Canonicalize "**equivalent**" schedule configurations
2. Identify "**dominating**" schedule configurations
3. **Prune** partial configurations which will lead to worse (or unacceptable results)

"Equivalent" Schedules

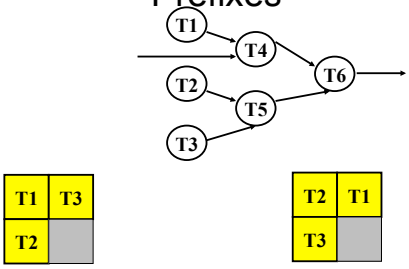
- If multiple resources of same type
  - assignment of task to particular resource at a particular timeslot is not distinguishing

Keep track of resource usage by capacity at time-slot.

"Equivalent" Schedule Prefixes



"Non-Equivalent" Schedule Prefixes

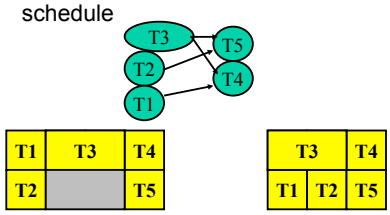


Pruning Prefixes

- Keep track of scheduled set
- Recognize when solving same sub-problem
  - Like dynamic programming finding same sub-problems
  - But no guarantee of small number of subproblems
    - set is power-set so 2^N
    - …but not all feasible,
      - so shape of graph may simplify

Dominant Schedules

- A strictly shorter schedule
  - scheduling the same or more tasks
  - will always be superior to the longer schedule



Pruning

- If can establish a particular schedule path will be worse than one we've already seen
  - we can discard it w/out further exploration
- In particular:
  - LB=current schedule time + lower_bound_estimate
  - if LB greater than known solution, prune

Pruning Techniques

Establish Lower Bound on schedule time

- Critical Path (ASAP schedule)
- Resource Bound

Alpha-Beta Search

- Generalization
  - keep both upper and lower bound estimates on partial schedule
    - Lower bounds from CP, RB
    - Upper bounds with List Scheduling
  - expand most promising paths
    - (least upper bound, least lower bound)
  - prune based on lower bounds exceeding known upper bound
  - (technique typically used in games/Chess)

Alpha-Beta

- Each scheduling decision will tighten
  - lower/upper bound estimates
- Can choose to expand
  - least current time (breadth first)
  - least lower bound remaining (depth first)
  - least lower bound estimate
  - least upper bound estimate
- Can control greediness
  - weighting lower/upper bound
  - selecting "most promising"

Note

- Aggressive pruning and ordering
  - can sometimes make polynomial time in practice
  - often cannot *prove* will be polynomial time
  - usually represents problem structure we still need to understand

Multiple Resources

- Works for multiple resource case
- Computing lower-bounds per resource
  - resource constrained
- Sometimes deal with resource coupling
  - *e.g.* must have 1 A and 1 B simultaneously or in fixed time slot relation
    - *e.g.* bus and memory port

Summary

- Resource estimates and refinement
- Branch-and-bound search
  - "equivalent" states
  - dominators
  - estimates/pruning

Admin

- Assignment 1 was due at class start
- Reading
  - Wednesday online
- Assignment 2 out
  - Part A due next Monday
  - Part B following

Big Ideas:

- Estimate Resource Usage
- Use dominators to reduce work
- Techniques:
  - Force-Directed
  - Search
    - Branch-and-Bound
    - Alpha-Beta