CS 152
Computer Architecture and Engineering
Lecture 23: The Final Chapter

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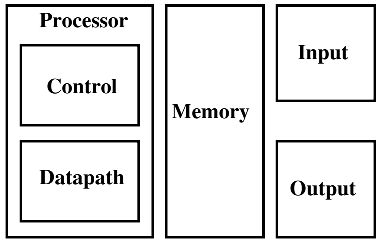
Outline of Today's Lecture

- Recap: What was covered in lectures
- Questions and Administrative Matters
- Classes to consider after CS 152
- 10 suggestions for a happy career
- Lessons from CS 152
- Your Cal Cultural Heritage (10 minutes)
- HKN evaluation of teaching staff

The Big Picture

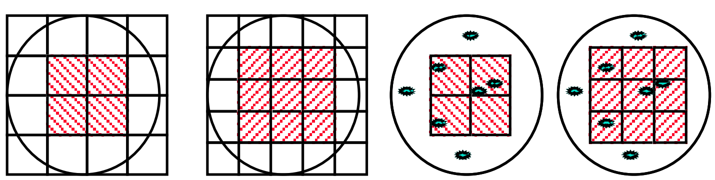
- Since 1946 all computers have had 5 components



Integrated Circuits Costs

$$\text{Die cost} = \frac{\text{Wafer cost}}{\text{Dies per Wafer} * \text{Die yield}}$$

$$\text{Dies per wafer} = \frac{\pi * (\text{Wafer\_diam} / 2)^2}{\text{Die Area}} - \frac{\pi * \text{Wafer\_diam}}{\sqrt{2 * \text{Die Area}}} - \text{Test dies} \approx \frac{\text{Wafer Area}}{\text{Die Area}}$$



$$\text{Die Yield} = \text{Wafer yield} * \left\{1 + \frac{\text{Defects\_per\_unit\_area} * \text{Die\_Area}}{\alpha}\right\}^{-\alpha}$$

Die Cost is goes roughly with the cube of the area.

Performance Evaluation Summary

$$\text{CPU time} = \frac{\text{Seconds}}{\text{Program}} = \frac{\text{Instructions}}{\text{Program}} \times \frac{\text{Cycles}}{\text{Instruction}} \times \frac{\text{Seconds}}{\text{Cycle}}$$

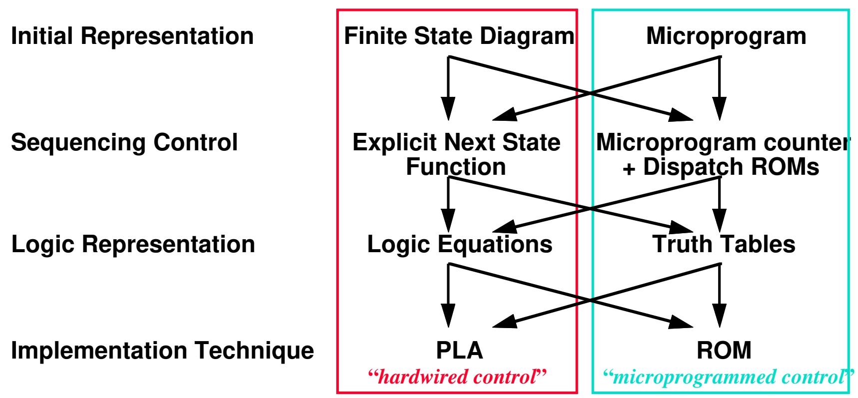
- Time is the measure of computer performance!
- Good products created when have:
  - Good benchmarks
  - Good ways to summarize performance
- If not good benchmarks and summary, then choice between improving product for real programs vs. improving product to get more sales=> sales almost always wins
- Remember Amdahl's Law: Speedup is limited by unimproved part of program

Arithmetic

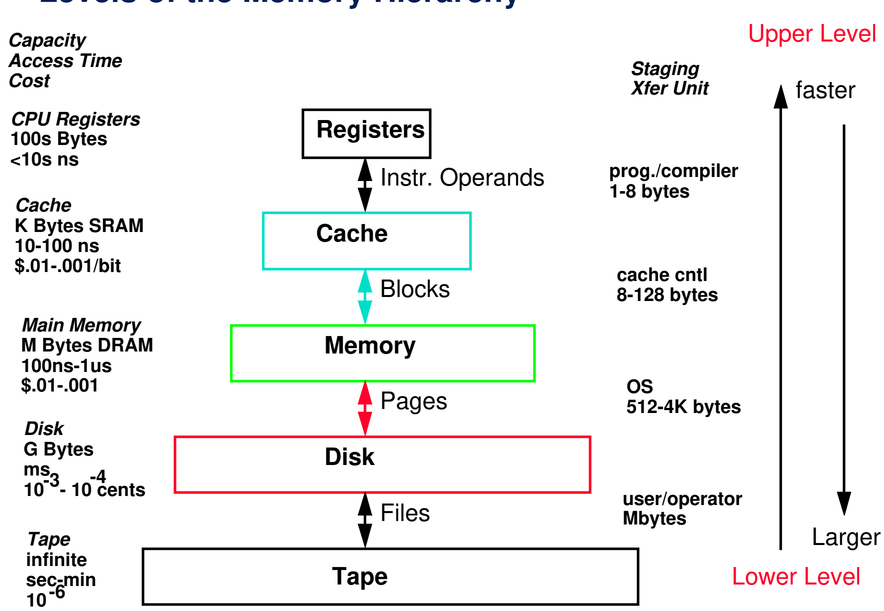
- Bits have no inherent meaning: operations determine whether they are really ASCII characters, integers, floating point numbers
- Divide can use same hardware as multiply: Hi & Lo registers in MIPS
- Floating point basically follows paper and pencil method of scientific notation using integer algorithms for multiply and divide of significands
- IEEE 754 requires good rounding; special values for NaN, Infinity
- Pentium: Difference between bugs that board designers must know about and bugs that potentially affect all users
  - Why not make public complete description of bugs in later category?
  - $200,000 cost in June to repair design
  - $500,000,000 loss in December in profits to replace bad parts
  - How much to repair Intel's reputation?
- What is technologists responsibility in disclosing bugs?

Control: Hardware vs. Microprogrammed

° **Control may be designed using one of several initial representations. The choice of sequence control, and how logic is represented, can then be determined independently; the control can then be implemented with one of several methods using a structured logic technique.**



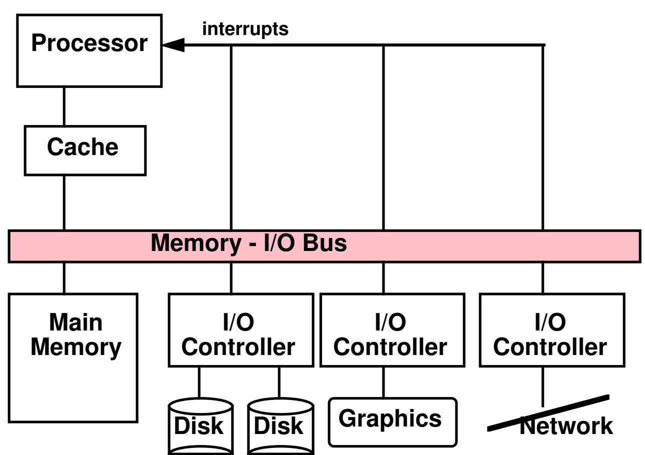
Levels of the Memory Hierarchy



Memory HIerarchy

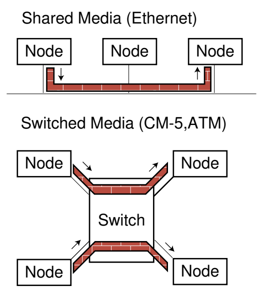
- The Principle of Locality:
  - Program access a relatively small portion of the address space at any instant of time.
    - Temporal Locality: Locality in Time
    - Spatial Locality: Locality in Space
- Three Major Categories of Cache Misses:
  - Compulsory Misses: sad facts of life. Example: cold start misses.
  - Conflict Misses: increase cache size and/or associativity.
    Nightmare Scenario: ping pong effect!
  - Capacity Misses: increase cache size
- Virtual Memory invented as another level of the hierarchy
  - Today VM allows many processes to share single memory without having to swap all processes to disk, protection more important
  - TLBs are important for fast translation/checking

I/O System Design Issues

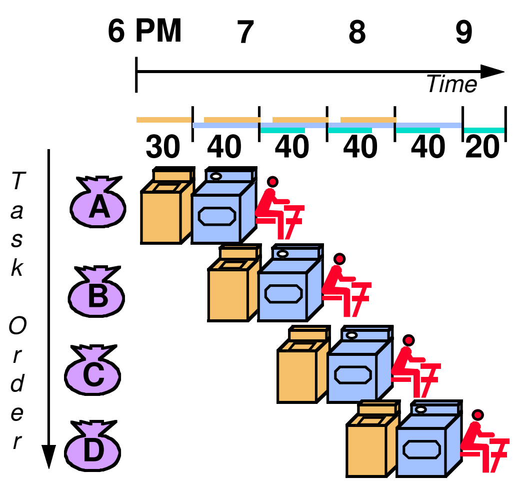


Interconnection Network Issues

- Advantages of Serial vs. Parallel lines:
  - No synchronizing signals
  - Higher clock rate and longer distance than parallel lines. (e.g., 60 MHz x 256 bits x 0.5 m vs. 155 MHz x 1 bit x 100 m)
    - Imperfections in the copper wires or integrated circuit pad drivers can cause skew in the arrival of signals, limiting the clock rate, and the length and number of the parallel lines.
- Switched vs. Shared Media: pairs communicate at same time: "point-to-point" connections



Pipelining Lessons



- Pipelining doesn't help latency of single task, it helps throughput of entire workload
- Pipeline rate limited by slowest pipeline stage
- Multiple tasks operating simultaneously
- Potential speedup = Number pipe stages
- Unbalanced lengths of pipe stages reduces speedup
- Time to "fill" pipeline and time to "drain" it reduces speedup

First Generation RISC Pipelines

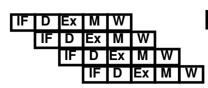
- All instructions follow same pipeline order ("static schedule").
- Register write in last stage
  - – Avoid WAW hazards
- All register reads performed in first stage after issue.
  - – Avoid WAR hazards
- Memory access in stage 4
  - – Avoid all memory hazards
- Control hazards resolved by delayed branch (with fast path)
- RAW hazards resolved by bypass, except on load results
which are resolved by fiat (delayed load).

Substantial pipelining with very little cost or complexity.
Machine organization is (slightly) exposed!
Relies very heavily on "hit assumption"of memory accesses in cache

How can the machine exploit available ILP?

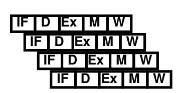
Technique / **Limitation**

- Pipelining



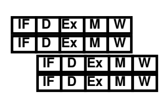
Issue rate,
FU stalls,
FU depth

- Super-pipeline
  - Issue 1 instr. / (fast) cycle
  - IF takes multiple cycles



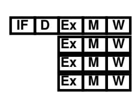
Clock skew,
FU stalls,
FU depth

- Super-scalar
  - Issue multiple scalar instructions per cycle



Hazard resolution

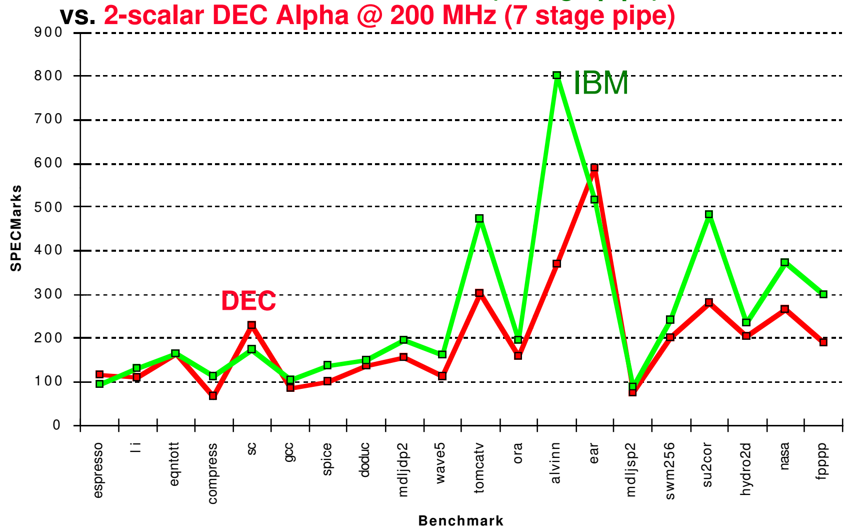
- VLIW
  - Each instruction specifies multiple scalar operations



Packing

Braniac vs. Speed Demon (1994)

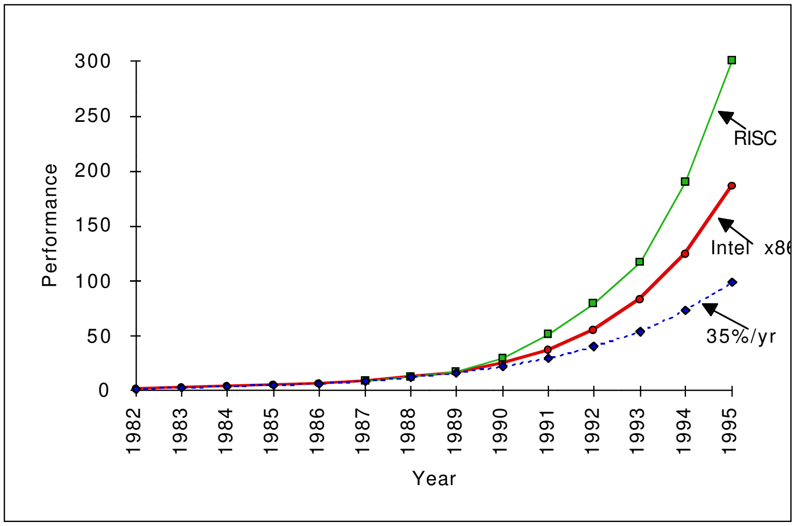
- 8-scalar IBM Power-2 @ 71.5 MHz (5 stage pipe)
  vs. 2-scalar DEC Alpha @ 200 MHz (7 stage pipe)



Performance Retrospective

- Theory of Algorithms & Compilers based on number of operations
- Compiler remove operations and “simplify” ops:
  Integer adds << Integer multiplies << FP adds << FP multiplies
  - Advanced pipelines => these operations take similar time
- As Clock rates get higher and pipelines are longer, instructions take less time but DRAMs only slightly faster (although much larger)
- Today time is a function of (ops, cache misses);
  FP multiply faster than integer multiply
- Given importance of caches, what does this mean to:
  - Compilers?
  - Data structures?
  - Algorithms?
- How do you tune performance on R10000?

Processor Performance



Questions and Administrative Matters (5 Minutes)

- **Projects due 4PM on Monday May 8 in 634 Soda (NOT THE BOX)**
- **Returning graded projects/homeworks now**
- **CS 152 questionairre: help us improve CS 152**
  - e.g., increased disk space, licenses, computers
  - e.g., reduced number of assignments, requirements
  - we will talk to Kevin M. about %#$! license server
  - your good idea goes on the form!

CS152: So what's in it for me? (from first lecture)

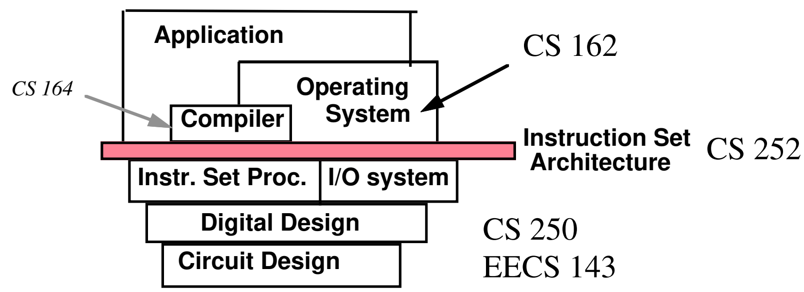
- In-depth understanding of the inner-workings of modern computers, their evolution, and trade-offs present at the hardware/software boundary.
  - Insight into fast/slow operations that are easy/hard to implementation hardware
- Experience with the *design process* in the context of a large complex (hardware) design.
  - Functional Spec --> Control & Datapath --> Physical implementation
  - Modern CAD tools
- Designer's "Intellectual" toolbox.

Simulate Industrial Environment

- Project teams must have at least 4 members
- Communicate with colleagues (team members)
  - What have you done?
  - What answers you need from others?
  - You must document your work!!!
  - Everyone must keep an on-line notebook
- Communicate with supervisor (TAs)
  - How is the team's plan?
  - Short progress reports are required:
    - What is the team's game plan?
    - What is each member's responsibility?

Beyond CS 152

E 190: Technical Communication
CS 169: Software Engineering



Rules to Remember (10)

First two laws of thermodynamics:

- You cannot get more energy out than you put in: you cannot win!
- Entropy: you cannot break even!

10. Laws of thermodynamics apply to life:
    - If you want things to get better, you need to work on it.
    - If you sit around and do nothing, things will get worse.

Rules to Remember (9)

10. Laws of thermodynamics apply to life.
    - If you want things to get better, you need to work on it.
    - If you sit around and do nothing, things will get worse.

° 9. If you want a particular job, don't reject yourself by making excuses.
    - Apply for it and let ***them*** decide whether you are good enough

Rules to Remember (8)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don't reject yourself by making excuses.

° 8. Don't worry what other people think. Worry how you can improve.
    - What other people think of you is their problem.
    - Your problem is how you plan to improve yourself.

Rules to Remember (7)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don't reject yourself by making excuses.
8. Don't worry what other people think. Worry how you can improve.

- 7. "Trying too hard" will never be the reason you fail.
  - Do everything you can, and then do more
  - It is better to try and fail than not try at all

Rules to Remember (6)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don't reject yourself by making excuses.
8. Don't worry what other people think. Worry how you can improve.
7. "Trying too hard" will never be the reason why you fail.

- 6. If you want to be treated special, treat others special.
  - Always be HONEST and FAIR
    (but you cannot and should not try to please everyone all the time)

Rules to Remember (5)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don’t reject yourself by making excuses.
8. Don’t worry what other people think. Worry how you can improve.
7. “Trying too hard” will never be the reason why you fail.
6. If you want to be treated special, treat others special.

◦ 5. Don’t be afraid of problems.
  - All you need is a plan.
  - Plan your life.
  - Live your plan.

Rules to Remember (4)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don’t reject yourself by making excuses.
8. Don’t worry what other people think. Worry how you can improve.
7. “Trying too hard” will never be the reason why you fail.
6. If you want to be treated special, treat others special.
5. Plan your life. Live your plan.

◦ 4. The most important steps of your plan: current and the next one.
  - The final goal of your plan may seem impossible
  - But you are “a OK” as long as you know:
    - What do you need to do right now?
    - What do you need to do next?
    - Don’t get depressed about mistakes you made yesterday.
    - Don’t get too excited about the good things you did.

Rules to Remember (3)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don’t reject yourself by making excuses.
8. Don’t worry what other people think. Worry how you can improve.
7. “Trying too hard” will never be the reason why you fail.
6. If you want to be treated special, treat others special.
5. Plan your life. Live your plan.
4. The most important steps of your plan: current and the next one.

° 3. Face reality: discover and reveal bad news as soon as possible.
   - You need to find out so you can change plan and move on.
   - Don’t tell your manager you are 1 week behind schedule one day before the deadline!

Rules to Remember (2)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don’t reject yourself by making excuses.
8. Don’t worry what other people think. Worry how you can improve.
7. “Trying too hard” will never be the reason why you fail.
6. If you want to be treated special, treat others special.
5. Plan your life. Live your plan.
4. The most important steps of your plan: current and the next one.
3. Face reality: discover and reveal bad news as soon as possible.

° 2. Don’t let problems at work affect your life at home.
   Don’t let problems at home affect your work.
   - Your family and friends don’t get paid to share your frustration.
   - Your coworkers don’t get paid to share your “home problems”.

Rules to Remember (1)

10. Laws of thermodynamics apply to life.
9. If you want a particular job, don't reject yourself by making excuses.
8. Don't worry what other people think. Worry how you can improve.
7. "Trying too hard" will never be the reason why you fail.
6. If you want to be treated special, treat others special.
5. Plan your life. Live your plan.
4. The most important steps of your plan: current and the next one.
3. Face reality: discover and reveal bad news as soon as possible.
2. Don't let problems at work affect your life at home.
   Don't let problems at home affect your work.

° 1. Stay focused!
  - Finish the thing you are doing before doing any "random walk" onto the next thing.
  - Your career is measured by tasks you ***finish***
    - NOT by clever ideas you only start

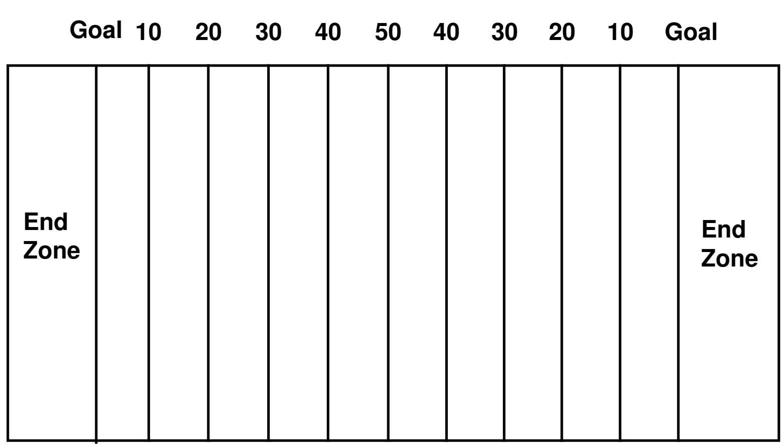
Summary: Things we Hope You Learned from 152

- Keep it simple and make it work
  - Fully test everything individually and then together
  - Retest everything whenever you make any changes
  - Last minute changes are big "no nos"
- Group dynamics. Communication is the key to success:
  - Be open with others of your expectations and problems
  - Everybody should be there on design meetings when key decisions are made and jobs are assigned
- Planning is very important:
  - Promise what you can deliver and deliver more you promise
  - Murphy's Law: things do break at the last minute
    - Don't make your plan base on the best case scenario
    - Freeze you design and don't make last minute changes
- Never give up! It is not over until you give up.

Cal Cultural Histroy: ABCs of American Football

- **Started with soccer; still 11 on a team, 2 teams, 1 ball, on a field; object is to move ball into "goal"; most goals wins**
- **New World changes the rules to increase scoring:**
  - **Carry ball with hands**
  - **Can toss ball to another player backwards or laterally (called a "lateral")**
- **How to stop players with ball? Grab them & Knock them down by making knee hit the ground ("tackle")**
- **Score by moving ball into goal ("cross the goal line" or "into the end zone") scoring a "touchdown" (6 points), or kicking ball between 2 poles ("goal posts") scoring a "field goal" (3, unless "extra point" after touchdown = 1)**
- **Kick ball to other team after score ("kickoff")**
- **Unlike soccer: has a timer that runs out; games ends when no time and person with ball is stopped**

Football Field



The Spectacle of Football

- American football is a speactle: musicians that march
- Bands from both schools at games; before, at halftime, after game
  - Game divided into 4 quarters;2 quarters = half
  - teams switch direction each quarter
- Archrival Stanford Stereotype: Private, Elitest, Snobs
- Stanford Band more like a drinking club; “Animal house”
  - Yell at Cal band during Cal’s performance
  - Plays one song: “All Right Now.”
- The Big Game: Cal vs. Stanford, winner gets a trophy (“The Axe”) to keep until next game
- 1982 Big Game (85th): Oldest rivalry west of Mississippi

1982 Big Game

- “There has never been anything in the history of college footbal to equal it for sheer madness.”
- Cal coach is Joe Kapp, former Cal player; tells team to play 100% for 60 minutes; 1st time as coach; lasts 5 years
- Stanford coach is Paul Wiggin, former Stanford player, lots of coaching experience; fired from job next year
- Stanford Quarterback is John Elway, who goes on to be a professional All Star Football player (still playing today)
- Stanford lost 4 games in last few minutes of game
- Stanford kicks field goal to lead 20-19 with 4 seconds left

Notes About “The Play”

- Cal only had 10 men on the field; last second another came on (170 pound Steve Dunn #3) & made key block
- Kevin Moen #26: never scored in 4 years at Cal
  - laterals to Rodgers
- Richard Rodgers #5: “Don’t fall with the ball.”
  - laterals to Garner
- Dwight Garner#43: 5’9” 185 pound running back
  - almost tackled, laterals to Ford
- Mariet Ford #1: 5’9”, 165 pound wide receiver
  - leg cramps, overhead lateral to Moen & block 3 players
- Moen cuts through Stanford band into end zone
- On the field: 144 member Stanford band, 3 cheerleaders, 3 members ofAxe comittee, + 11 extra football players;
- “weakest part of the Stanford defense was the woodwinds”
- 4 Cal football players play + Stanford Trombone player (Gary Tyrrell) hold reunion every year

Your Cal Cutural History

- Cal students/alumni heritage is the greatest college football play in > 100 years
- Cal students/alumni remain optimistic, no matter how gloomy it may look to others
- Cal students/alumni work hard and play hard
- Cal students/alumni do not give up!
- Cal students/alumni triumph over great odds!
- Cal students/alumni take pity on Stanford students/alumni