Take home message

1. **How to measure errors?** Absolute and relative
2. **Error types.** Errors in math model; input data; Approximation (discretization, convergence, roundoff) errors.
3. Roundoff error can behave erratically; prefer domination by discretization error
4. **Big O notation**
6. Ill-conditioned v.s. well-conditioned problem
Case Study
The Patriot Missile Failure
The Patriot Missile Failure

On February 25, 1991, during the Gulf War, an American Patriot Missile battery in Dharan, Saudi Arabia, failed to track and intercept an incoming Iraqi Scud missile. The Scud struck an American Army barracks, killing 28 soldiers and injuring around 100 other people.

What happened?
Based on a report of the General Accounting Office

An inaccurate calculation of the time since boot due to computer arithmetic errors.

The time in tenths of second as measured by the system's internal clock was multiplied by 1/10 to produce the time in seconds.

This calculation was performed using a 24 bit fixed point register.

In particular, the value 1/10, which has a non-terminating binary expansion, was chopped at 24 bits after the radix point.

The small chopping error, when multiplied by the large number giving the time in tenths of a second, led to a significant error.

**This was a matter of Rounding Error!**

http://www.ima.umn.edu/~arnold/disasters/patriot.html
Error accumulation

Patriot battery ran for 100 hours

1/10 seconds in binary: $0.00011001100110011001100...$

Stored in 24 bit register as: $0.00011001100110011001100$

Error: $0.0000000000000000000000011001100$ roughly $0.000000095$ decimal

Multiply by 100 hours and tens of a second: $0.000000095 \times 100 \times 60 \times 60 \times 10 = 0.34$ seconds

Velocity of Scud is 1,676 m per second, it travels $1676 \times 0.34$ roughly 500 meters

Patriot therefore failed to track and intercept the target Scud!

http://www.ima.umn.edu/~arnold/disasters/patriot.html
For your procrastination reading list

2. Known SW bugs: [http://www5.in.tum.de/~huckle/bugse.html](http://www5.in.tum.de/~huckle/bugse.html)
News and Announcement

1. Lecture 1 posted online.
2. Guest speaker on 8/30:
   Dr. Mark Kim (SCI):
   Fixed-Rate Compressed Floating-Point Arrays
THANKS!

Any questions?
You can contact us via
1. Canvas
2. Sourabh Palande: sampla@cs.utah.edu
3. Bei Wang Phillips: beiwang@sci.utah.edu
Extra Notes

So it goes.
Credits

Special thanks to all the people who made and released these awesome resources for free:

✗ Presentation template by SlidesCarnival
✗ Photographs by Unsplash