Richard W. Hamming

Learning to Learn

The Art of Doing Science and Engineering

Session 20: Simulation III

How do you get good answers?

Garbage in, garbage out

- quality of input determines the quality of output
- universally accepted
- not universally true

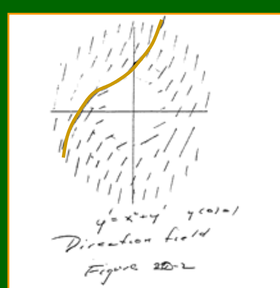
How are you performing the simulation?

- do your equations make physical sense?
- do you understand the phenomenon?

Understanding and Direction Fields

Many simulations rely on differential equations

- Use a simple test to understand the behavior of the equation
- Does this behavior approximate reality?
- Which is wrong, reality or the equation?



Understanding and Direction Fields

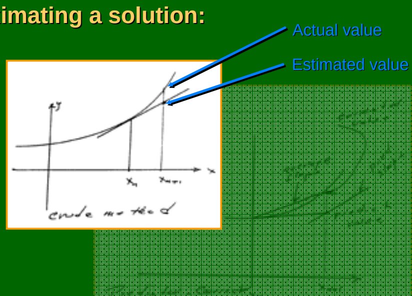
Use simple, direct methodology to test assumptions EARLY

- Direction fields are merely a simple way to understand simple equations
- Start with a wide view of the problem and the proposed solution.

Direction Fields

When approximating a solution:

Just calculating the slope of the line at any one point gives an increasingly inaccurate answer.



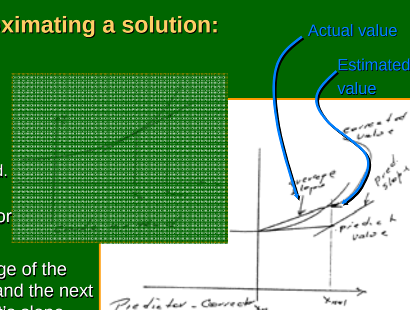
Direction Fields

When approximating a solution:

Euler's method gives a much more satisfying fit than crude method.

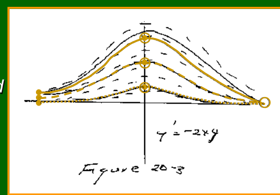
Predictor-corrector method:

Use the average of the current slope and the next predicted point's slope



Garbage In, Garbage Out

- In some situations:
  - *High fidelity data goes bad*
- In other situations:
  - *Low fidelity data makes good*
- Convergent direction fields effectively reduce error
- Divergent direction fields effectively induce error



Directional Fields and Step-size

Using the predictor-corrector method:

- Optimize your solution
- Use current and predicted points' slopes
  - *Too close, double step size*
  - *Too far, halve step size*
- Different step-sizes in the same simulation

NASA

Straight-line vs. Polynomial Approximation

Euler used straight lines for approximation

- Simple, straight-forward

More likely today to use 4th degree polynomials

- Several points used to develop an equation
- The derivative of the equation at the point is the input
- The polynomial fit should be good, but it will not be exact and you will have "corners"

Recursive Digital Filter

Approximation by polynomials is equivalent to digital filter theory

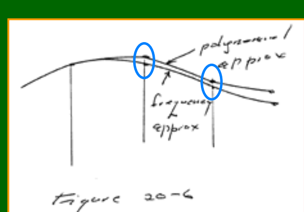
- Sample several points
- Produce predicted value
- Make corrections
- Sample again…

But they are not the same!

Numerical Analysis vs. Filter Theory

Digital Filters deal in frequencies rather than equations

- No "corners" at the step transitions
- Fidelity may be lower
- The "feel" will be better



Which is Better?

Depends on what you're simulating

- Mars lander
  - *For the pilot--needs "feel"*
- Mars voyage
  - *For the physicist--needs fidelity*

Naval Safety Center "Brownshoes in Action Comix" 1988

GIGO, Revisited

Nike missile testing

- Test failures in September 1946

Los Alamos atomic bomb calculations

- Estimates produce accurate results

www.redstone.army.mil

DOE Nevada Operations Office

Direction Fields, GIGO, and the Simulator

Not all situations can be reduced to a single, simple formula

- "[T]he whole computation must be understood as a whole"
  - *Is there a feedback compensation which occurs?*
  - *Are there values which are "vitally" out in the open?*
- Understanding offers protection from overkill
  - *Don't need:*
    - too many accurate values
    - too many precise components

Rorschach Test

A quest for meaning in the meaningless

- Inkblot test "reveal[s] things about yourself"
- A system's design and testing can just as easily reveal things about the engineer, and not the problem or the solution
- It is too easy to manipulate things in a simulation to get the expected results instead of "reality"
- As such, results are often called into question based on the assumptions which drive them, a process which allows more of the same to occur, not always less
- Double-blind experiments

Conclusions

"Simulation is essential to answer the 'What if…?', but it is full of danger…"

- Not to be trusted on its face
- Can be a tool of decisive action
- Can be a tool of waffling, delaying, and mediocrity
- Know what questions to ask
- Know what details to understand