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1990

**Learning to Learn: The Art of Doing Science  
and Engineering, Session 20:**

Hamming, Richard W.

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<http://hdl.handle.net/10945/59484>

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# 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?

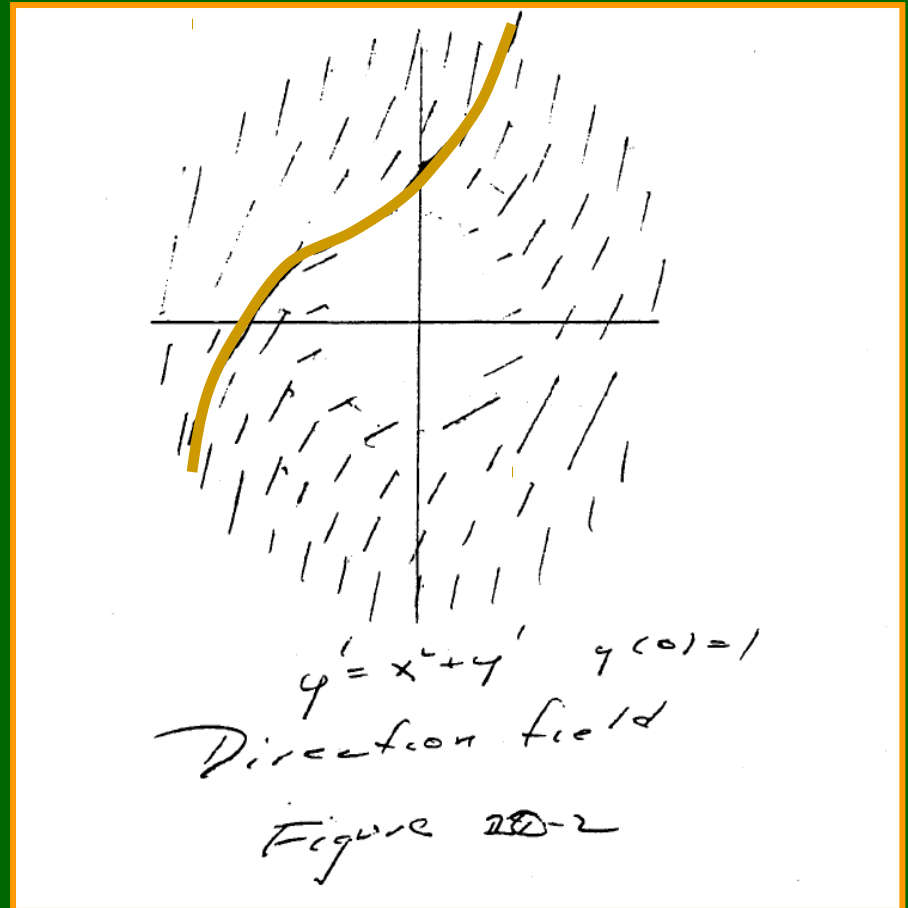
- do your equations make physical sense?
- do you understand the phenomenon?

# 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**

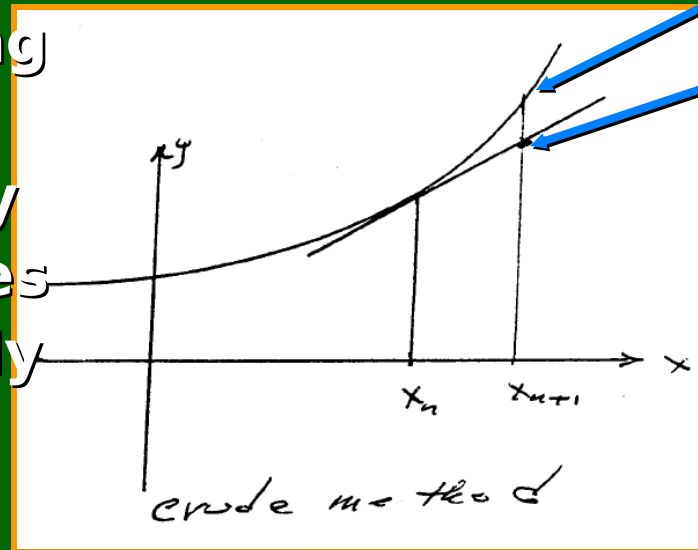
- Direction fields are merely a simple way to understand simple equations
- Start with a wide view of the problem and the proposed solution.



# Direction Fields

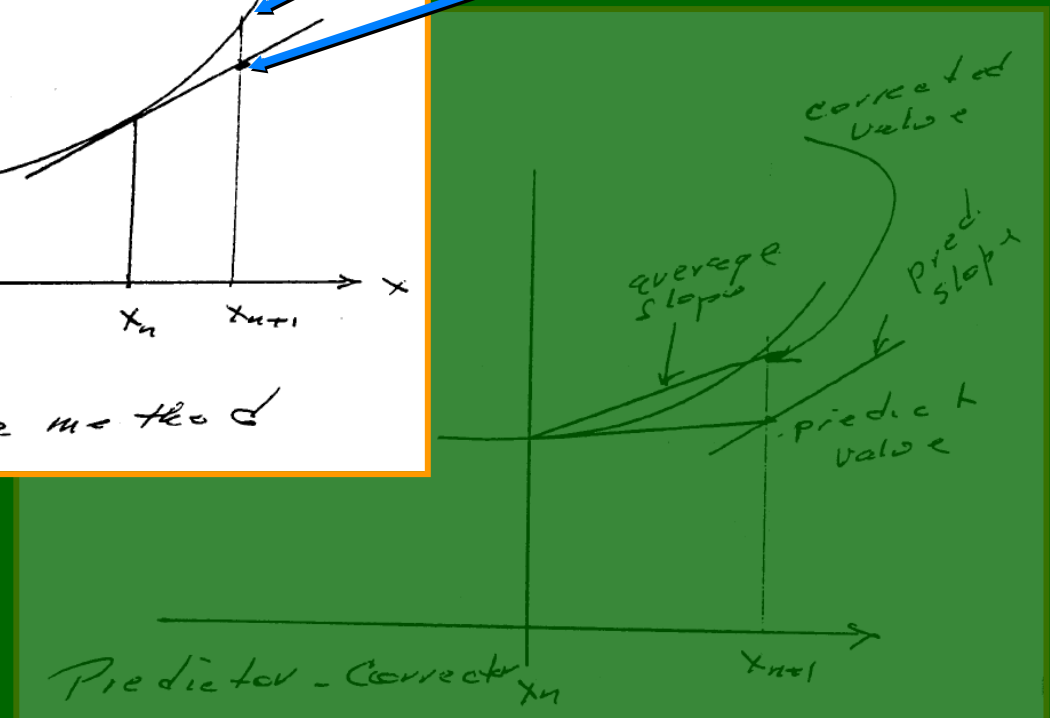
**When approximating a solution:**

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



Actual value

Estimated value





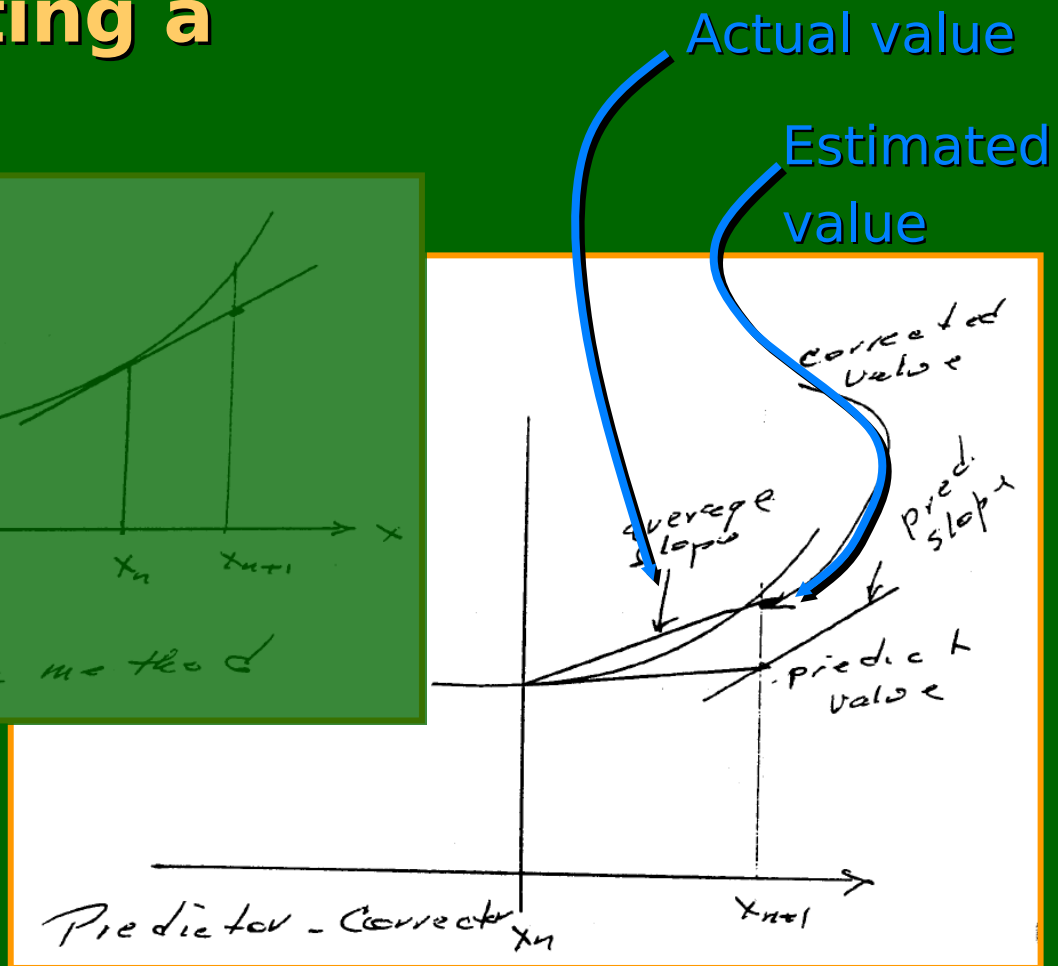
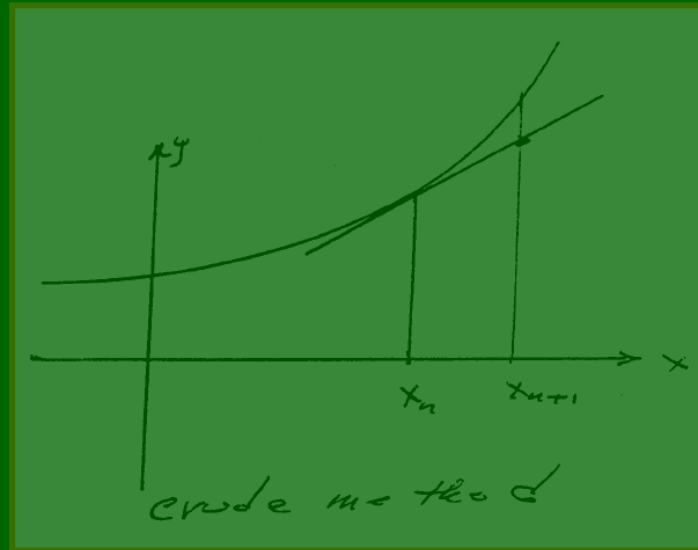
# Direction Fields

## When approximating a solution:

Euler's method gives a much more satisfying fit

than crude method. Predictor-corrector method:

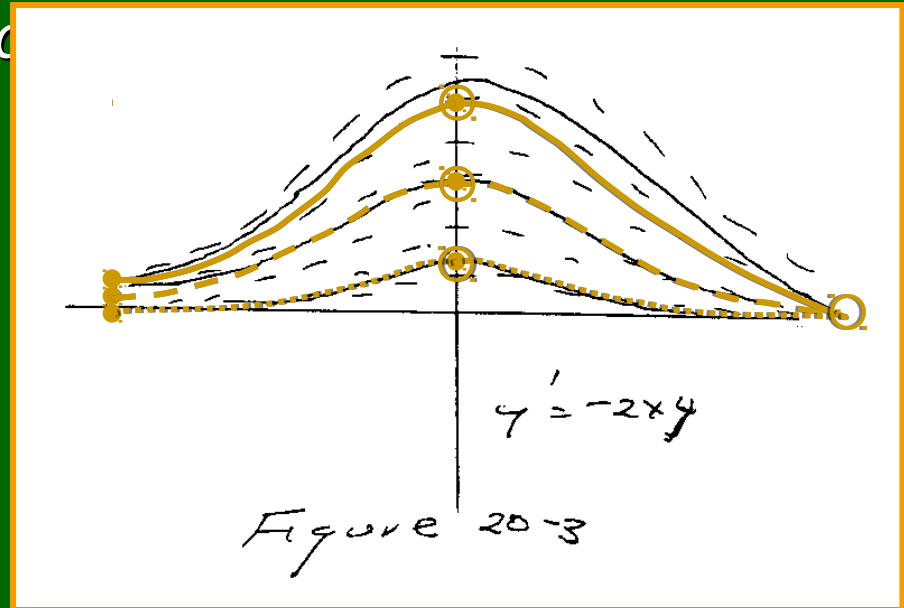
Use the average of the current slope and the next predicted point's slope





# Garbage In, Garbage Out

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



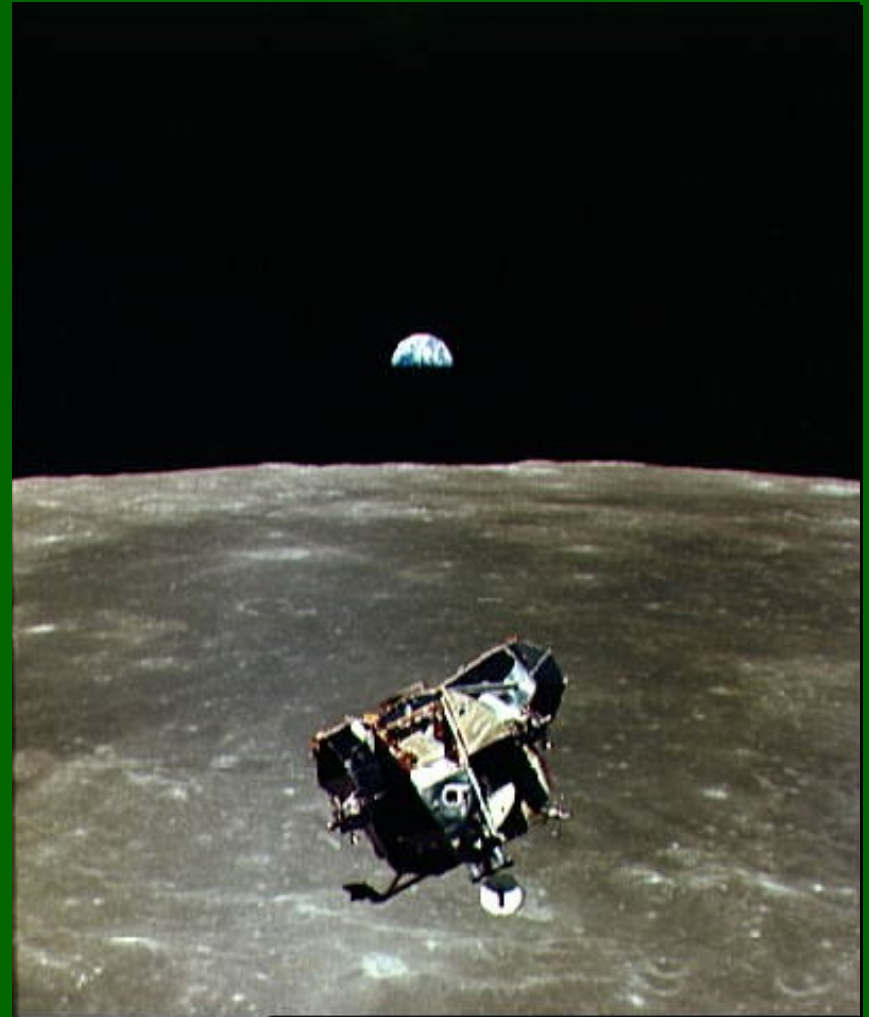


# Directional Fields and Step-size



## 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...

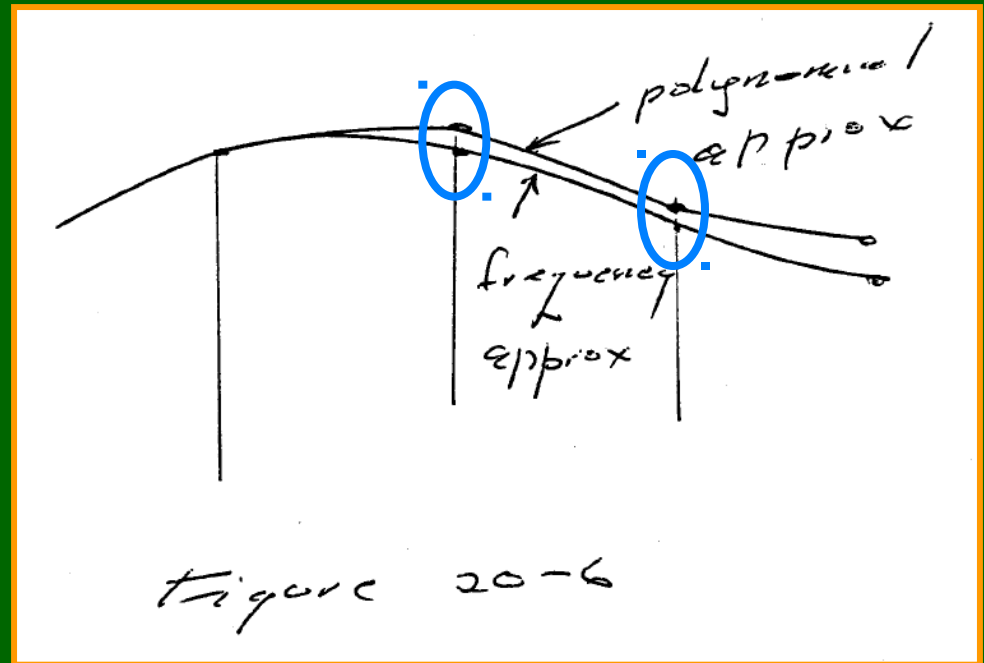
**But they are not the same!**

# 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

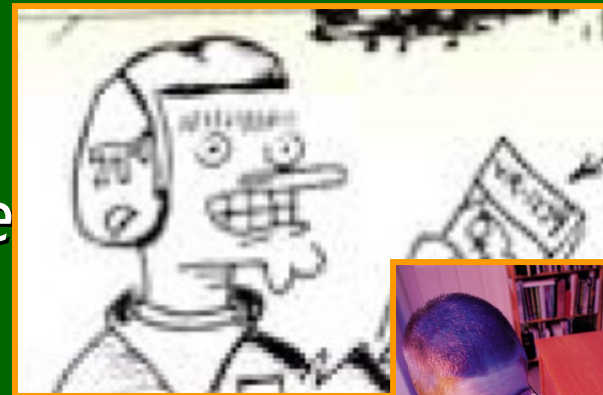




# Which is Better?

## Depends on what you're simulating

- Mars lander
  - *For the pilot--needs "feel"*



Naval Safety Center "Brownshoes in Action Comix" 1988

- Mars voyage
  - *For the physicist--needs fidelity*





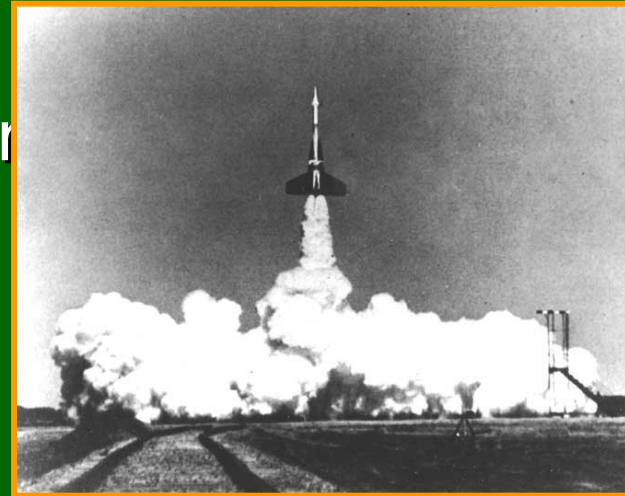
# GIGO, Revisited

## Nike missile testing

- Test failures in September 1946

## Los Alamos atomic bomb calculations

- Estimates produce accurate results



[www.redstone.army.mil](http://www.redstone.army.mil)



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# 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:*
    - <sup>2</sup> too many accurate values
    - <sup>2</sup> 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