Zero-Knowledge Proofs

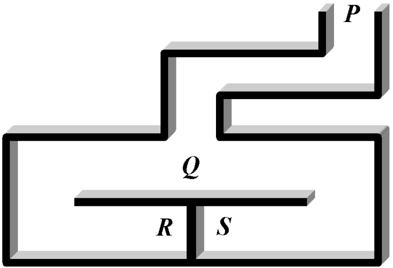
Showing you *can* do something, without showing how

Alex Dehnert

6.UAT

Fall 2011

Problem: Ali Baba's Cave

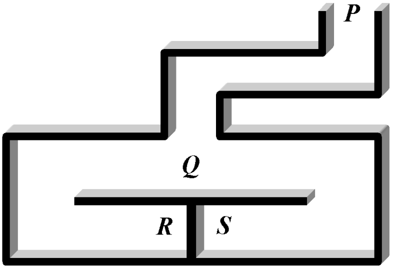


- Imagine that you (Peggy) are exploring a cave with a friend
- You know a secret password to get through the door between R and S
- You want to prove to your friend Victor that you know the password, without him finding out the password.

Image: RSA Laboratories

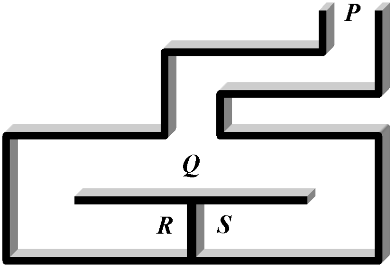
Solution

- Victor stands outside at P
- Peggy vanishes into the cave and stands at R or S
- Victor comes back in, stands at Q, and calls out which side Peggy should return by
- Peggy returns as requested



What if Peggy cheats?

- Victor stands outside at P
- Peggy picks R or S to hide at
- Victor comes back in, stands at Q, and calls out which side Peggy should return by
- If Peggy picked the correct side, she tricks Victor; otherwise, she has to admit she lied
- If Victor does this enough times, Peggy will guess wrong (one trial, 50% she succeeds; two trials, 25%; etc.)



Zero-Knowledge Proofs

Goal: Peggy (prover) wants to convince Victor (verifier) of something

Convincing If true, an honest prover can always convince an honest verifier

No cheating If false, a dishonest prover can only rarely convince an honest verifier

Zero knowledge If true, a cheating verifier cannot learn anything more than that it is true.

General Structure

Peggy: Prepare

Peggy: Commit

Victor: Challenge

Peggy: Respond

General Structure

Peggy: Prepare	Victor stands outside Peggy vanishes into the cave
Peggy: Commit	
Victor: Challenge	
Peggy: Respond	

General Structure

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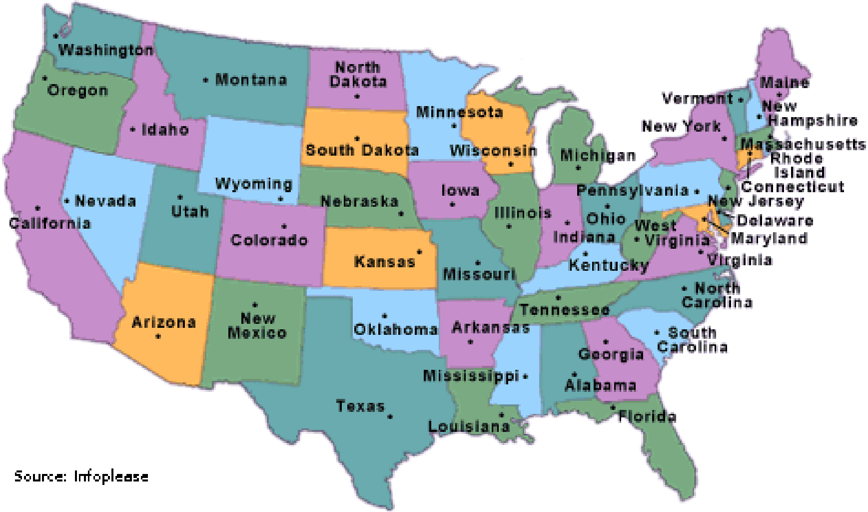
General Structure

Peggy: Prepare	Victor stands outside Peggy vanishes into the cave
Peggy: Commit	Victor comes back in, . . .
Victor: Challenge	. . . and calls out which side Peggy should return by
Peggy: Respond	Peggy returns as requested

Map 3-coloring

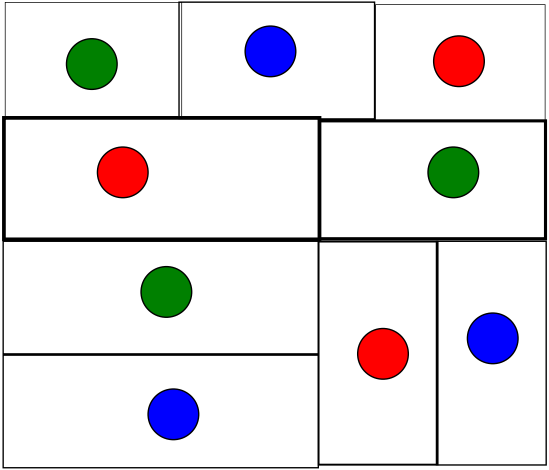
Given a map, prove that it can be colored using only three colors (and that you know a coloring).



Source: Infoplease

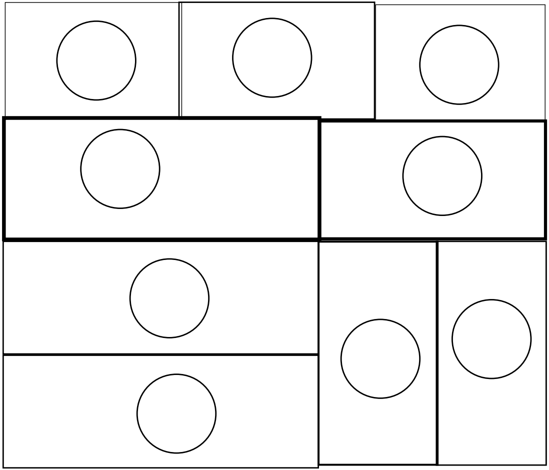
Map coloring ZKP

Prepare



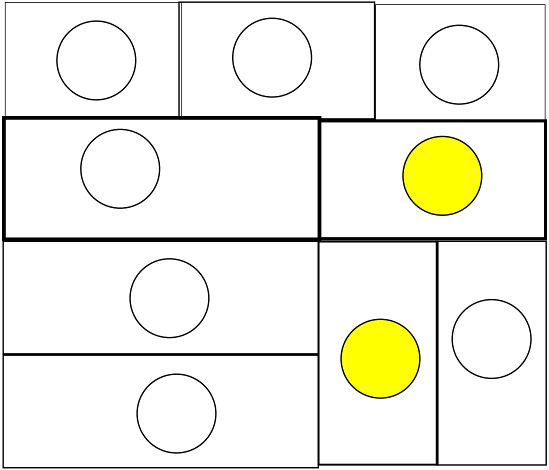
Map coloring ZKP

Commit



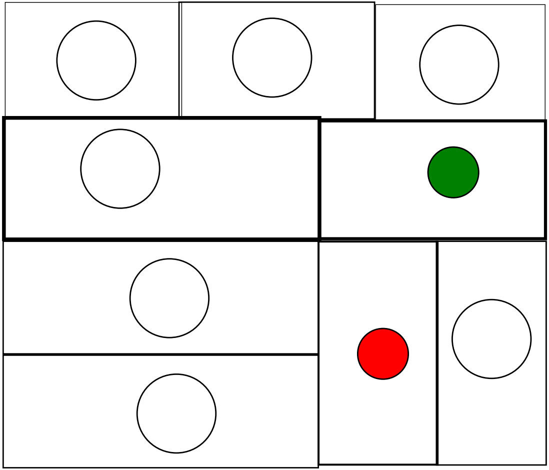
Map coloring ZKP

Challenge



Map coloring ZKP

Respond



Possible application: Proof of identity

- Numerous cases where you want to prove who you are
- Example: authorize a credit card transaction
- Don't want stores to be able to charge you for more stuff later
- Use zero-knowledge proof to prove who you are, instead of a credit card number you keep secret

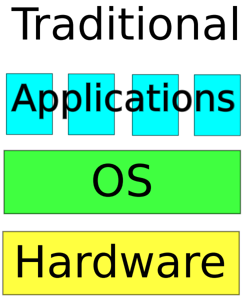
Using VProbes for Intrusion Detection

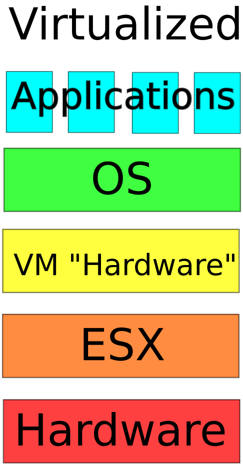
Alex Dehnert

VMware Intern, Summer 2011
Massachussetts Institute of Technology, S.B. 2012

Thursday, September 15, 2011

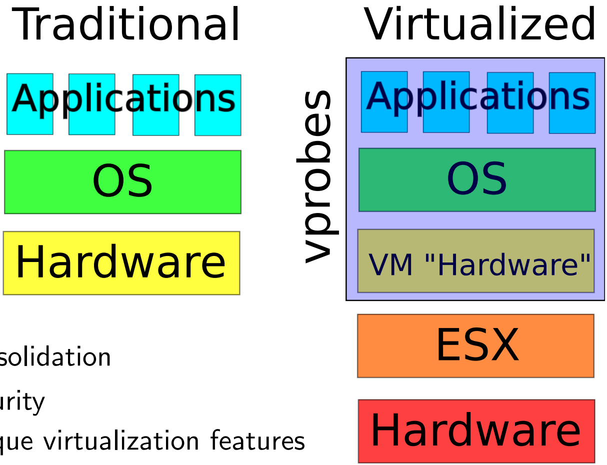
Virtualization





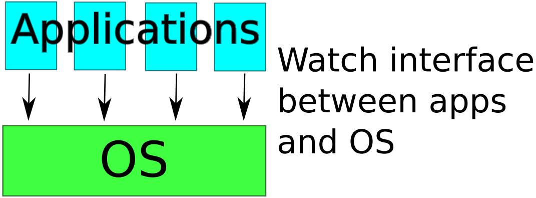
- Consolidation
- Security
- Unique virtualization features

Virtualization



- Consolidation
- Security
- Unique virtualization features
  - vprobes

vprobes IDS



- Use vprobes to watch application/OS communication
- Build a profile of normal behavior
- Alert when abnormal behavior occurs

Cost of Intrusions

$114 billion	Total global cost of cybercrime annually, as estimated by Symantec
$75 billion	2011 spending on IT security for US companies, according to the Ponemon Institute
$170 million	Cost to Sony of the recent PlayStation Network hack, including shutting down PSN, network security improvements, etc.

Sources: The Fiscal Times, Huffington Post

Intrusion Detection in Virtual Machines

Alex Dehnert

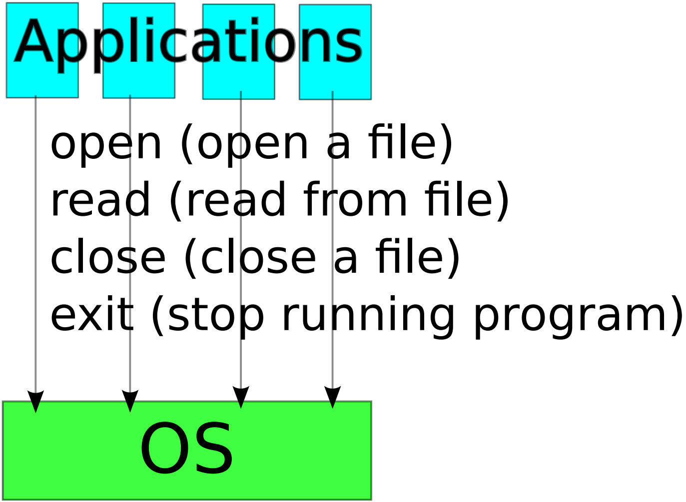
VI-A – VMware

Fall 2011

Problem

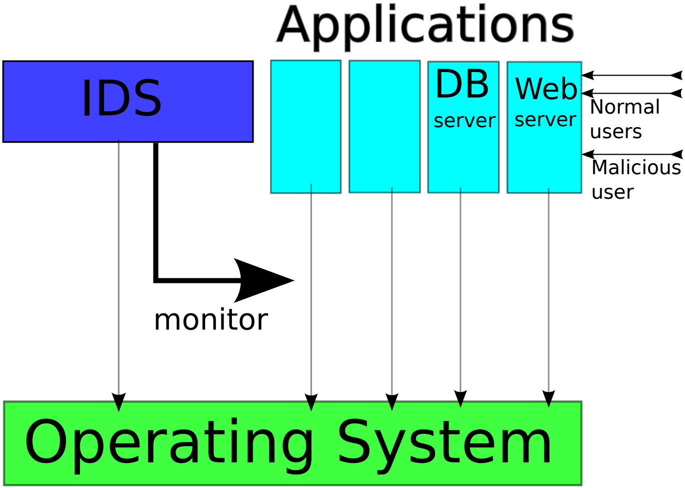
- Security is a growing issue
- Huge amounts of money are being spent, both to defend against attacks and to clean up after them
- Host-based intrusion detection systems monitor servers to detect attacks
- Security software is sometimes specifically targeted

System calls (syscalls)

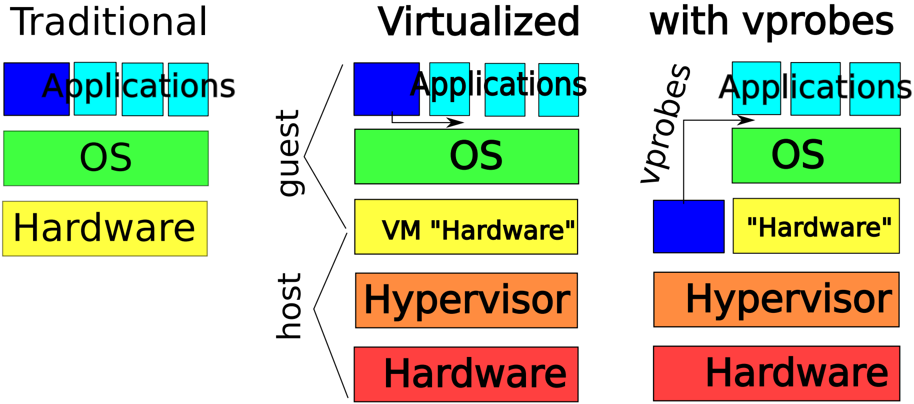


Intrusion detection

- Rich variety of work involving host-based intrusion detection
- Many based on patterns of system calls



How can virtual machines help?



Goal

Provide an intrusion detection system that is robust against attacks from malware, by leveraging vprobes to run the agent on the host

Prior Art

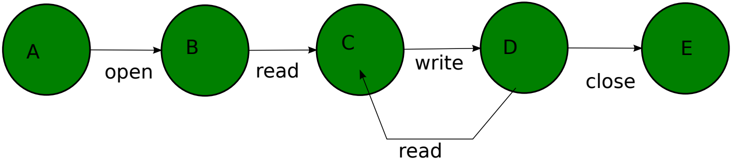
Much previous work on how to determine whether or not some sequence of syscalls is allowed

Prior Art: Custom rules

- Hand-written to match whatever the server in question is doing
- "Only allow the web server to access files under /var/www/"
- "Only allow the ssh server binary to bind to port 22"

Prior Art: Finite Automata

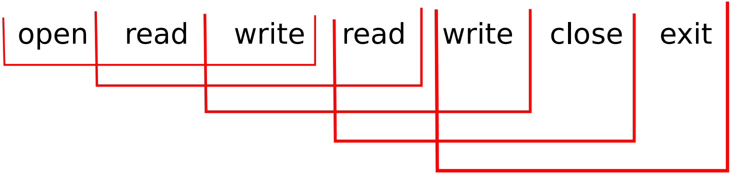
- Maintain current "state" associated with the syscalls so far (and other info)
- Define transitions between the various states
- When the appropriate syscall is seen, transition to the appropriate new state:



- If an unfamiliar syscall is made, alert

Prior Art: stide

- Sequence Time-Delay Embedding
- Sequences (n-grams) of syscalls



- Look at rolling window of twenty sequences at a time. If enough of them are unknown, alert.

What's new?

- Intrusion detection based on syscalls *isn't* — plenty of people have done that
- However, generally, that's vulnerable to attacks against the agent
- So, develop a version that gathers data using vprobes

Work required

- vprobe script to get syscall information from the kernel (Summer 2011)
- Build analysis modules (begun Summer 2011)
- Build up collection of exploits and normal behaviors to test against

Timeline

- Week 1 Get set up at VMware again
- Week 2 Re-familiarize with vprobes
- Week 3 Find off-the-shelf exploits for Apache and other services
- Week 4 Write a custom Apache exploit
- Week 5 More exploit-writing
- Week 6 Review literature on intrusion detection again; begin writing analyzer (e.g., finite automata)
- Week 7 Continue literature-based analyzer
- Week 8 Start custom analyzer (e.g., SVM)
- Week 9 Continue custom analyzer
- Week 10 Code cleanup and begin code review
- Week 11 Finish code review; begin writing report
- Week 12 Finish writing report

Risks

Big risk: schedule slippage Room to cut in both the exploit finding/writing and the analyzers

Can't come up with a novel analyzer Not key to the project. The main novelty is supposed to be in the vprobes component, anyway.

vprobes not powerful enough My team is the vprobes team. We can probably add required features.

Conclusion

- Security becoming increasingly important
- Host-based intrusion detection vulnerable to the agent being attacked
- Project: *Enhance effectiveness of intrusion detection systems by moving the vulnerable agent onto the host, and use vprobes to look inside the VM*
- Extensive literature exists on how to examine the data the agent/vprobes gather

Compton Scattering and the Klein-Nishina Formula

Daniel J. Fremont

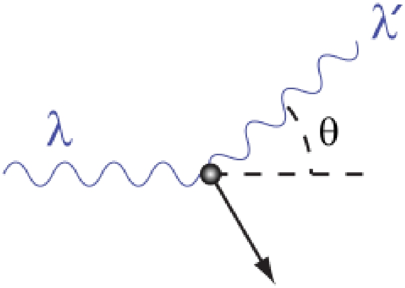
8.13
Massachusetts Institute of Technology

History

- Compton's x-ray diffraction experiments (1920-2)
  - Wavelength shift in scattered radiation
  - Explanation using photon momentum
- Wilson, Bothe detect recoil electron (1923)
- Wave-particle duality (de Broglie, Schrödinger)

Compton Scattering Theory

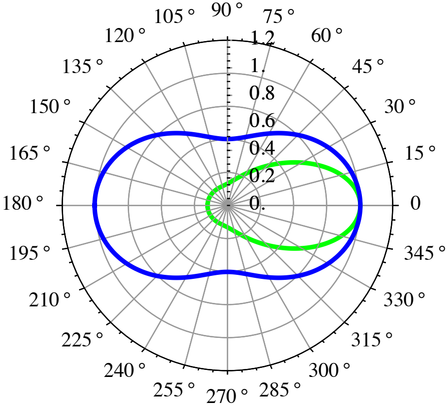
- Billiard-ball style collisions
- Relativistic energy: $E^2 = p^2c^2 + m^2c^4$



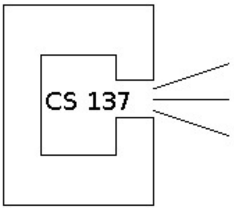
$$\Delta\lambda = \frac{h}{mc}(1 - \cos\theta)$$

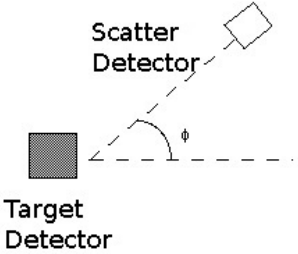
Scattering Intensities

- Classical treatment: Thomson cross-section
  - Only valid for low energies
- Relativistic treatment: Klein-Nishina formula



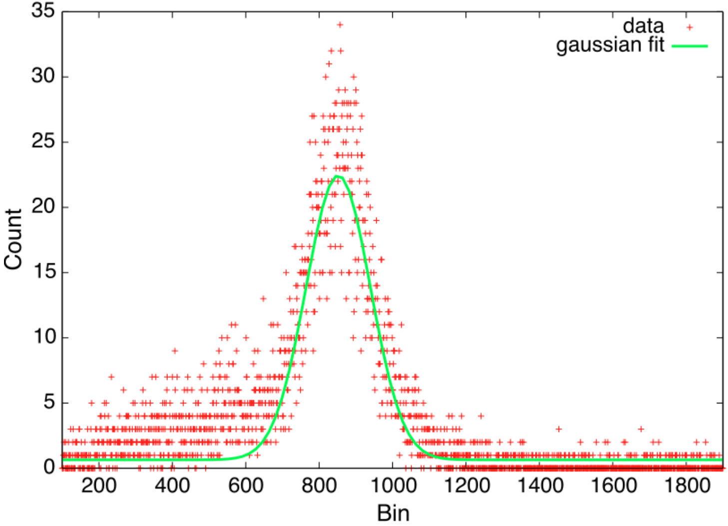
Apparatus





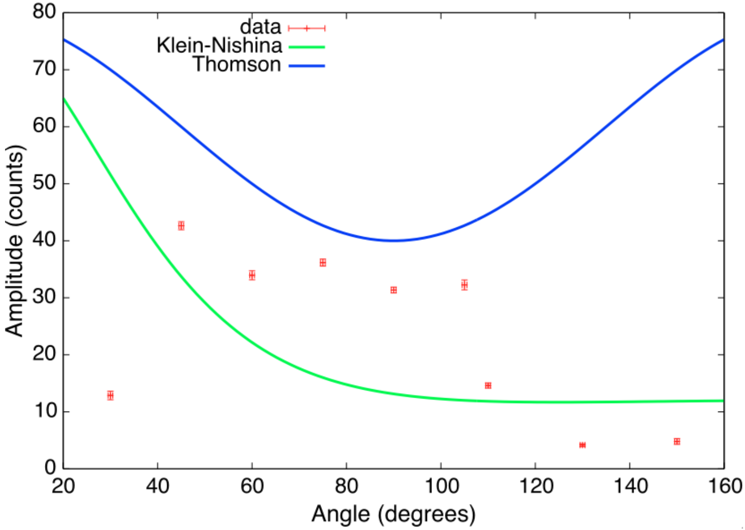
- Discriminators filter out noise
- Coincidence detector selects Compton events

Data



$$\chi_r^2 = 0.95$$

Amplitudes

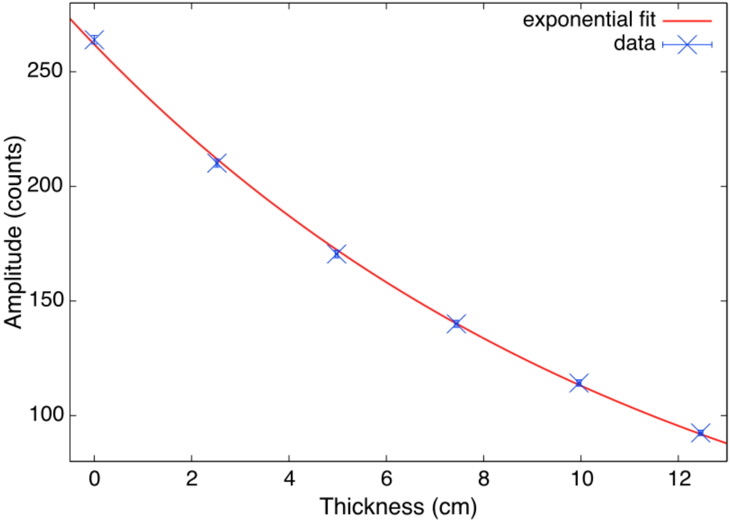


data
Klein-Nishina
Thomson
Amplitude (counts)
Angle (degrees)
0
10
20
30
40
50
60
70
80
20
40
60
80
100
120
140
160

Amplitude Results

- Classically-expected increase for large θ not observed
- Large systematic errors
  - Unusually weak signal at 30° — likely discriminated against
  - Scintillator efficiency
  - Detector drift
- Errors too significant to verify Klein-Nishina; however data definitely inconsistent with Thomson model

Attenuation



$$\chi_r^2 = 1.00$$

Attenuation Results

- Measured electron cross-section: $(2.50 \pm 0.025) \cdot 10^{-29}\, m^2$
  - Klein-Nishina prediction: $2.56 \cdot 10^{-29}\, m^2$ ($\approx 2\,\sigma$ off)
  - Thomson prediction: $6.65 \cdot 10^{-29}\, m^2$ ($\approx 166\,\sigma$ off!)
- Small systematic error
  - Some scattered photons detected
  - Detector drift
- Relativistic effects dominant: Klein-Nishina model much more accurate than classical Thomson model

Summary

- Systematic errors in amplitude data too large to allow verification of Klein-Nishina, but data definitely inconsistent with classical prediction
- Attenuation data strongly supports Klein-Nishina result over Thomson
- Necessity of relativistic quantum description of photons and electrons

Questions?

- History of Compton Scattering
- Scattering Theory
- Amplitude Experiment
- Attenuation Experiment

Electron–Xenon Scattering: The Ramsauer-Townsend Effect

Daniel J. Fremont

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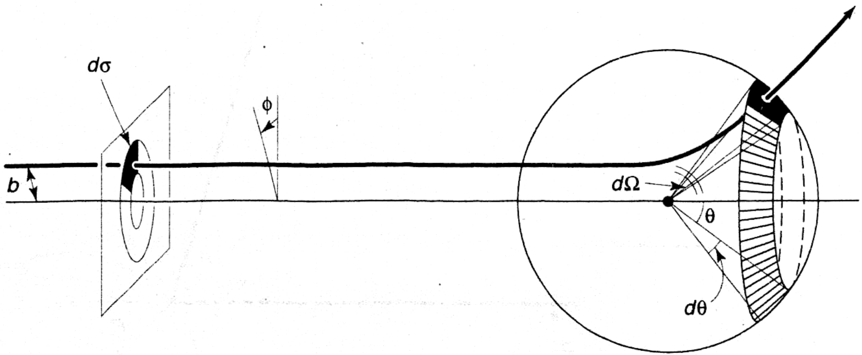
History of Ramsauer-Townsend

- Ramsauer (1921) discovers unexpected behavior in scattering experiments
- Townsend and Bailey (1922) confirm effect using a different method
- Bohr proposes interference of matter waves
- Effect explained using Schrödinger equation (1927-31)

Scattering

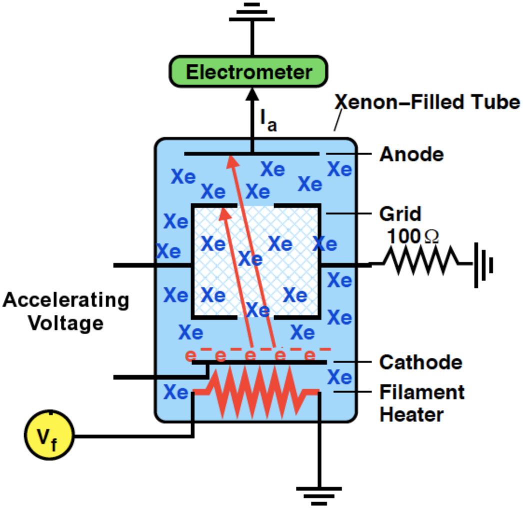


- $\mathrm{d}\sigma = D(\theta)\,\mathrm{d}\Omega$
- $\sigma(E) = \int D(\theta)\,\mathrm{d}\Omega$

Matter Waves and Interference

- Electrons and atoms cannot be treated as billiard balls
- Objects are diffuse, described by a wave function
- Interference between wave functions can produce unexpected effects
- Ramsauer-Townsend: $\sigma = 0$ for a particular energy

Apparatus



- Can freeze out Xe using liquid nitrogen

Calculating the Cross-Section

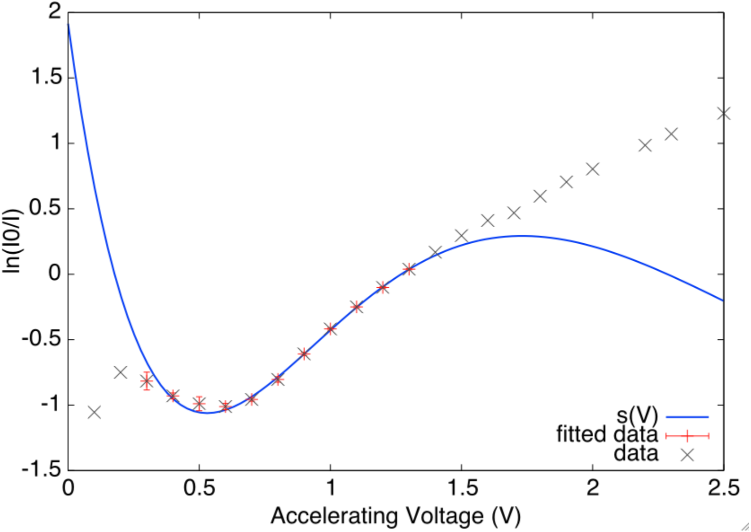
- Uniform gas density $\rightarrow$ constant scattering probability for a fixed distance

$$I = I_0 \, e^{-\frac{L}{\lambda}}$$

$$\frac{1}{\lambda} = n \, \sigma$$

$$\sigma(V) = \frac{1}{nL} \ln \left[\frac{I_0 \, (V)}{I \, (V)} \right]$$

Cross-Section Measurements



$$\chi_r^2 = 1.93$$

Results

- Minimum σ occurs at $0.53 \pm 0.077\ V$
  - Significantly off from true value of 0.9 V
- Random errors insufficient
- Systematic errors
  - Contact potential
  - Nonzero initial electron energy
  - Unequal filament temperatures
- Corrected value: $0.88 \pm 0.092\ V$

Improvements and Extensions

- Additional experiments to determine contact potential and initial electron energy
- Collect more data in vicinity of minimum σ
- Determine voltage necessary to get equal filament temperatures

Summary

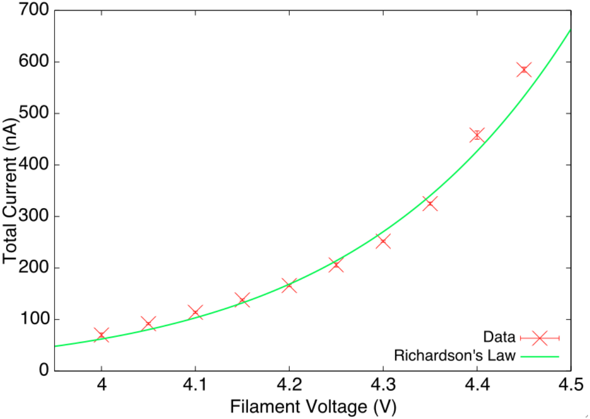
- Observed the Ramsauer-Townsend effect in electron–Xenon collisions
- Found minimum cross-section near expected energy
- Provided evidence for interference in matter waves and quantum theory

Questions?

- History of Ramsauer-Townsend
- Scattering
- Matter Waves
- Dependence of cross section on energy

Richardson's Law

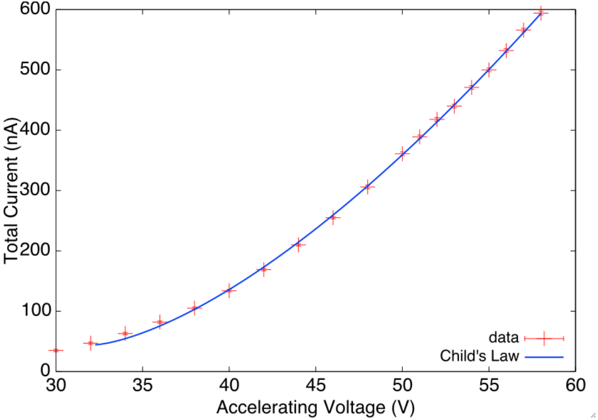
- $I \propto T^2 e^{\frac{-W}{kT}}$
- Only radiative heat transfer $\rightarrow V^2 \propto T^4$



$$\chi_r^2 = 44.7$$

Child's Law

- $I \propto V^{\frac{3}{2}}$



$$\chi_r^2 = 4.59$$

Nuclear Magnetic Resonance: Effect of Paramagnetic Ions on Relaxation Times

Daniel J. Fremont

8.13 — Junior Lab
Massachusetts Institute of Technology

Outline

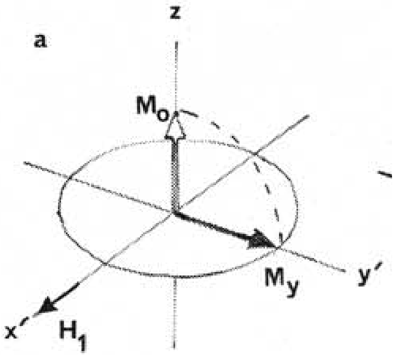
- Nuclear Magnetic Resonance
- Relaxation and Paramagnetic Ions
- A Useful Tool

History of NMR

- Rabi (1937) predicts and first observes NMR
- Purcell and Bloch (1945) measure relaxation times and their dependence on chemical properties
- Chemical shifts discovered (1950-1)
- Lauterbur (1973) applies NMR to medical imaging

Pulsed NMR

- Nuclear spins precess around static magnetic field
- Oscillatory perpendicular field $\rightarrow$ nutation
- Perpendicular spin component induces measurable current



Spin-Lattice Relaxation (T1)

- Return of spins to thermal equilibrium
- Energy transferred into molecular motions
- Lattice frequencies must be close to Larmor frequency

Spin-Spin Relaxation (T2)

- Loss of phase coherence
- Interactions between nearby spins

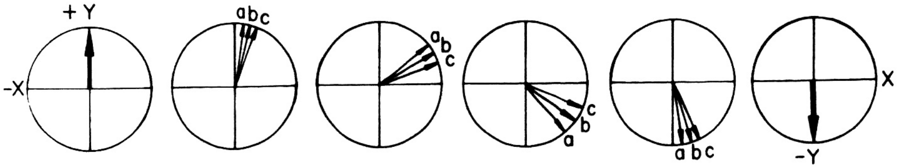
Paramagnetic Ions

- Enormous magnetic moments (≈1000 times proton)
- Much larger interaction energies → smaller relaxation times
- Slow local field variations → additional T2 mechanism

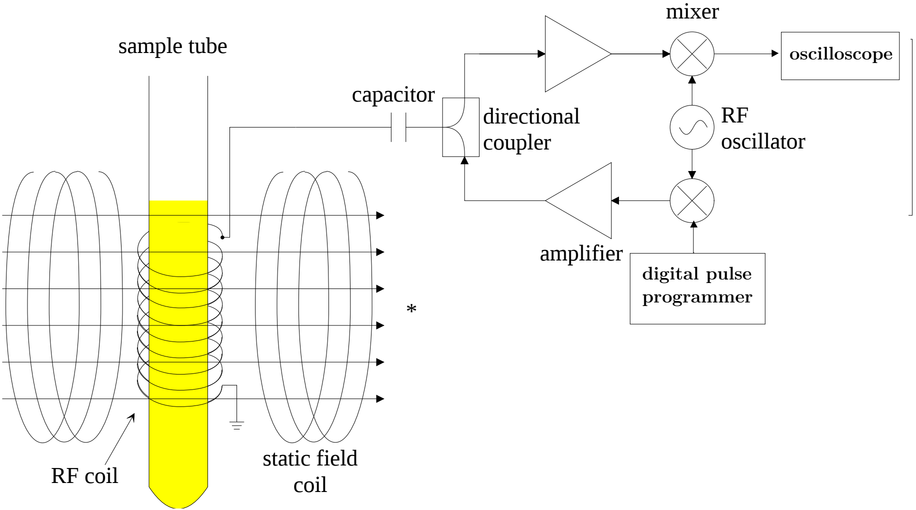
- $\frac{1}{T1} \propto$ ion concentration
- $\frac{1}{T2}$ more strongly affected

Spin Echoes

- Measuring relaxation directly has problems
  - Proximity to driving pulse
  - Inhomogeneity in static field alters observed T2
- Use 180° pulses to produce spin echoes (Hahn 1950)
  - Reverses phase decoherence from inhomogeneity

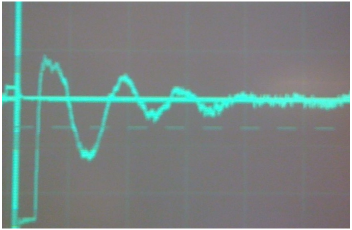


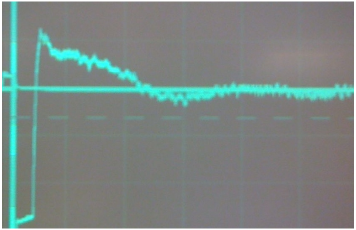
Apparatus


mixer
oscilloscope
sample tube
capacitor
directional
coupler
RF
oscillator
amplifier
digital pulse
programmer
*
RF coil
static field
coil

Finding Resonance

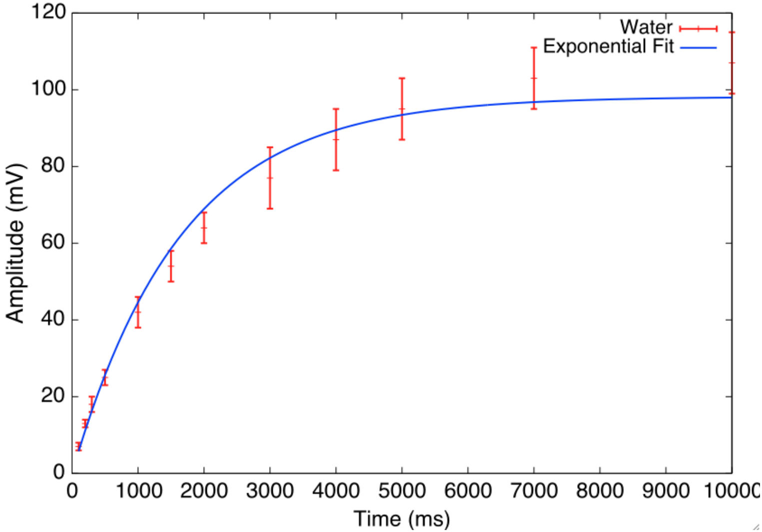
- Minimize beats
  - $\nu_{beats} = |\nu_{pulses} - \nu_{Larmor}|$





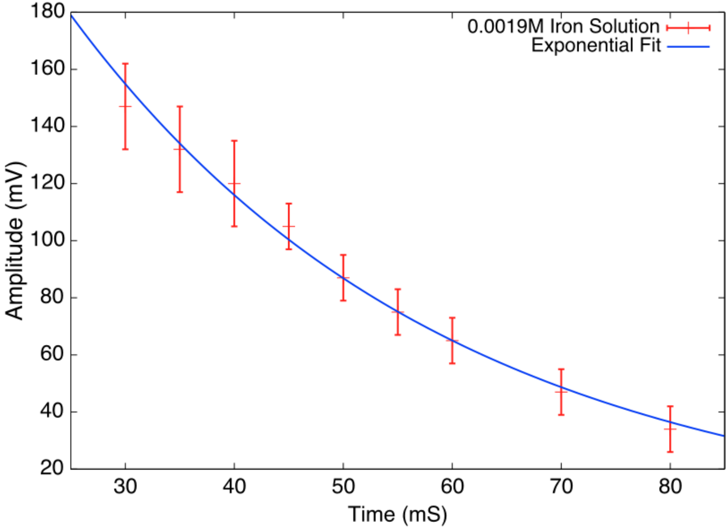
- Find most uniform B field
  - Inhomogeneity $\rightarrow$ different resonances $\rightarrow$ weaker signal
- Result: $(1.424 \pm 0.083) \cdot 10^{-26}$ J/T (3% off accepted value)

T1 Measurement



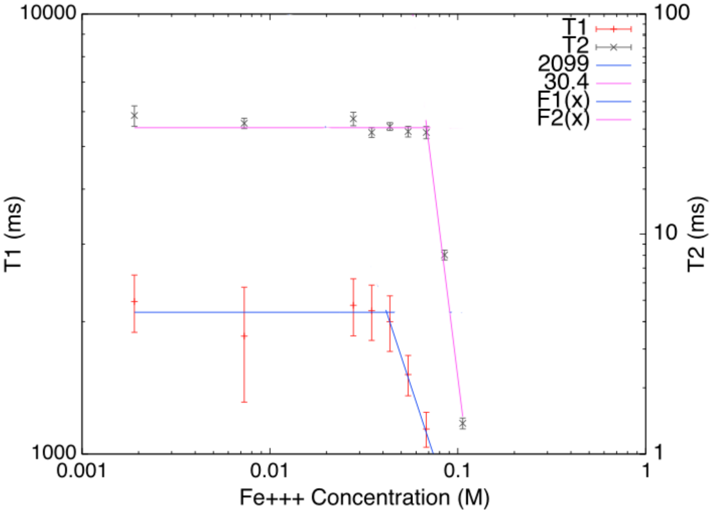
$$T1 = (2108 \pm 240)ms \qquad \chi_r^2 = 1.13$$

T2 Measurement



$$T2 = (8.86 \pm 0.16)ms \qquad \chi_r^2 = 0.13$$

Effect of Fe^{3+} Ions on T1 and T2



T_1 slope = -1.3 ± 0.4

T_1 $\chi_r^2 = 0.07$

T_2 slope = -6.9 ± 0.2

T_2 $\chi_r^2 = 12$

Results

- Proton magnetic moment: $(1.424 \pm 0.083) \cdot 10^{-26}$ J/T
  - Accepted value: $1.411 \cdot 10^{-26}$ J/T
- $\frac{1}{T1}$ grows linearly with Fe^{3+} concentration
- $\frac{1}{T2}$ grows faster than linearly with Fe^{3+} concentration

Improvements and Extensions

- More stable probe setup to allow more accurate determinations of field strength
- Greater sensitivity to allow use of higher concentrations
- Removing dissolved oxygen

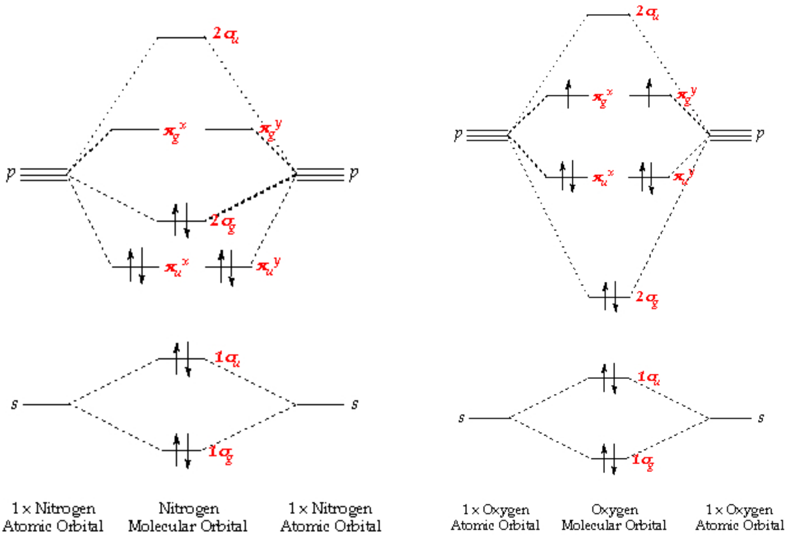
Summary

- Observed NMR in protons at the expected frequency
- Verified expected effects of Fe^{3+} ions on relaxation times
- Suggested usefulness of NMR in chemical analysis

Questions?

- History of NMR
- Pulsed NMR
- Spin-Lattice and Spin-Spin Relaxation
- Spin Echoes
- Proton Larmor Frequency
- Effects of Fe^{3+} ions on Relaxation Times

Paramagnetism: N_2 vs. O_2



Observation of the Photoelectric Effect

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Massachusetts Institute of Technology

History of a phenomenon

Discovery

- Hertz's radio experiments (1886-7)
- Ultraviolet light and electricity

Investigation

- Lenard's experiment (1902)
- Energies independent of intensity
- But dependent on frequency!

Understanding

- Einstein's explanation (1905)
- Light quanta with $E \propto \nu$
- Millikan's experiments (1912-5)

Einstein's theory

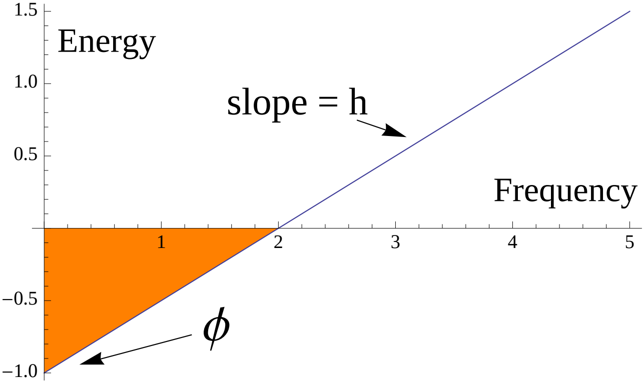
- Planck's quantized oscillators
- Photons, with $E = h\nu$
- Intensity $\equiv$ number of photons
- One photon, one electron

$\Downarrow$

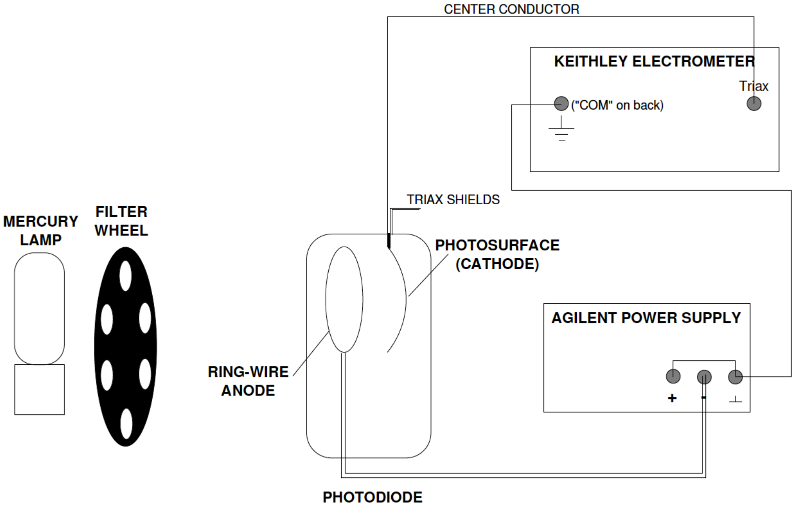
- Energy of emitted electrons independent of intensity
- Energy dependent on frequency
- Minimum cutoff frequency

Einstein's theory

$$KE_{e^-} = h\nu - \phi$$

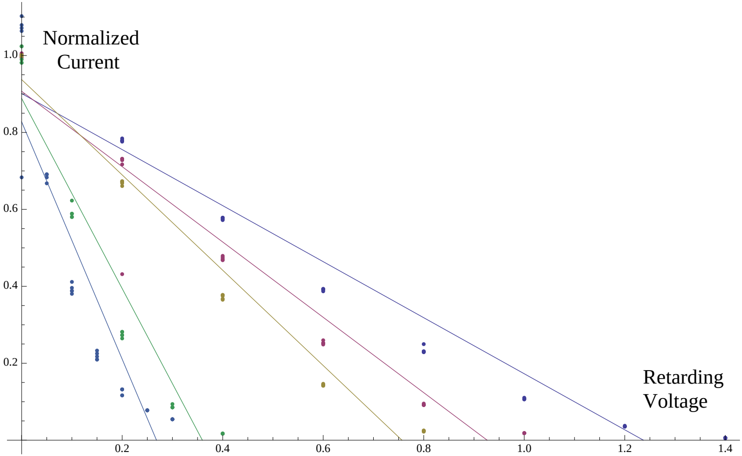


Experiment Setup



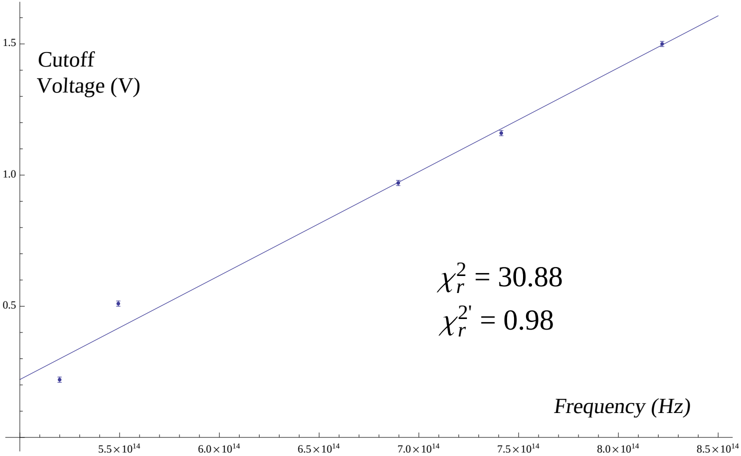
Slightly modified from experiment lab guide (`http://web.mit.edu/8.13/www/intro2.shtml`).

Current vs. Retarding Voltage



- Some expected features, with some extras
- Theoretical model?

Cutoff Voltage vs. Frequency



- Large χ^2 for small ν
- However, near-linear relationship as expected

Results and Errors

- $h = (6.348 \pm 0.0626) \cdot 10^{-34}\ \mathrm{J \cdot s}$
  - $\approx$ 4.2% off of true value ($\approx$ 4.5 times estimated error)
- $\phi = 1.76 \pm 0.026\ \mathrm{eV}$
  - $\approx$ 23% off of true value ($\approx$ 21 times estimated error)

- Random Errors
  - Precision of instruments
  - Small compared to...
- Systematic Errors
  - Ambient light
  - Light striking the anode
  - Cutoff voltage bias
  - Variation of ϕ

- Various possibilities for systematics, but probably not due to measurement error
- Disparity in error makes some possibilities less likely

Summary

- $h = (6.348 \pm 0.0626) \cdot 10^{-34}\ \mathrm{J \cdot s}$
- $\phi = 1.76 \pm 0.026\ \mathrm{eV}$
- Photoelectric effect well described by Einstein's model
  - Linear dependence of cutoff voltage on frequency
- Particle-like nature of light

Questions?

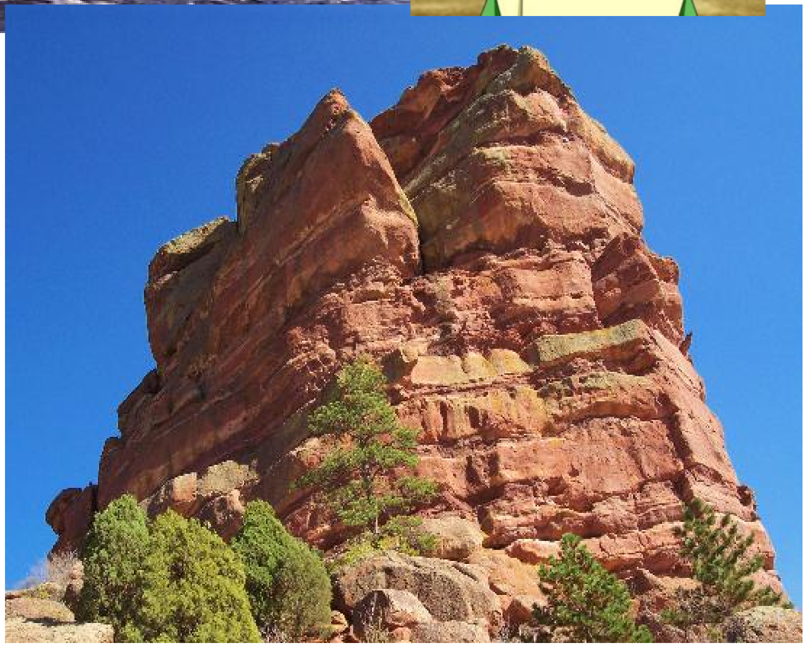
Rock Paper Scissors:

Real Professional Strategy

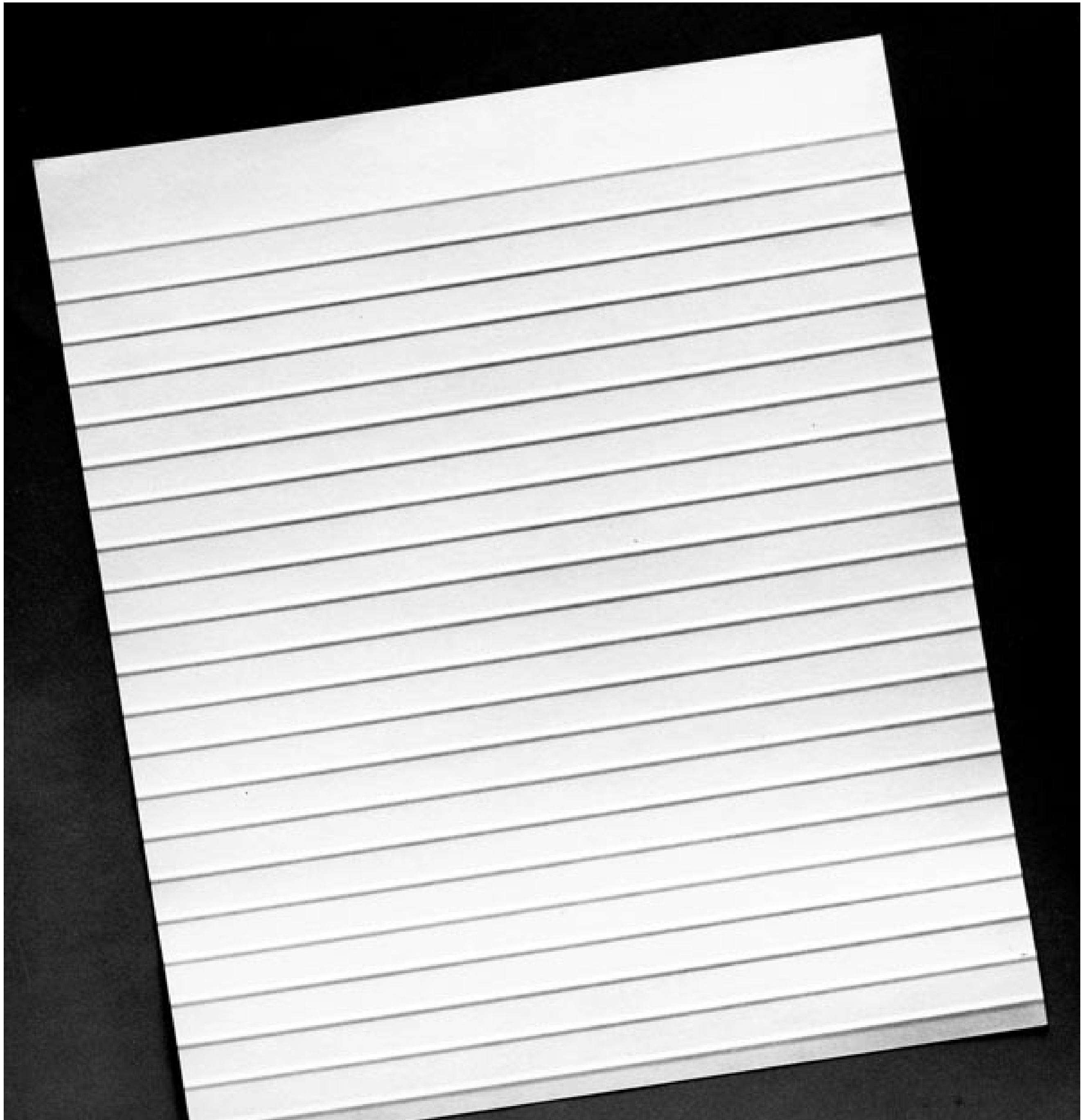
Nathan Benjamin & Xavier Jackson
(nathanb@mit.edu, jaxxson@mit.edu)

Rock

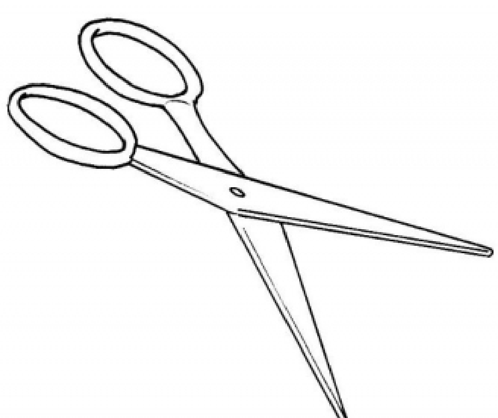



Paper



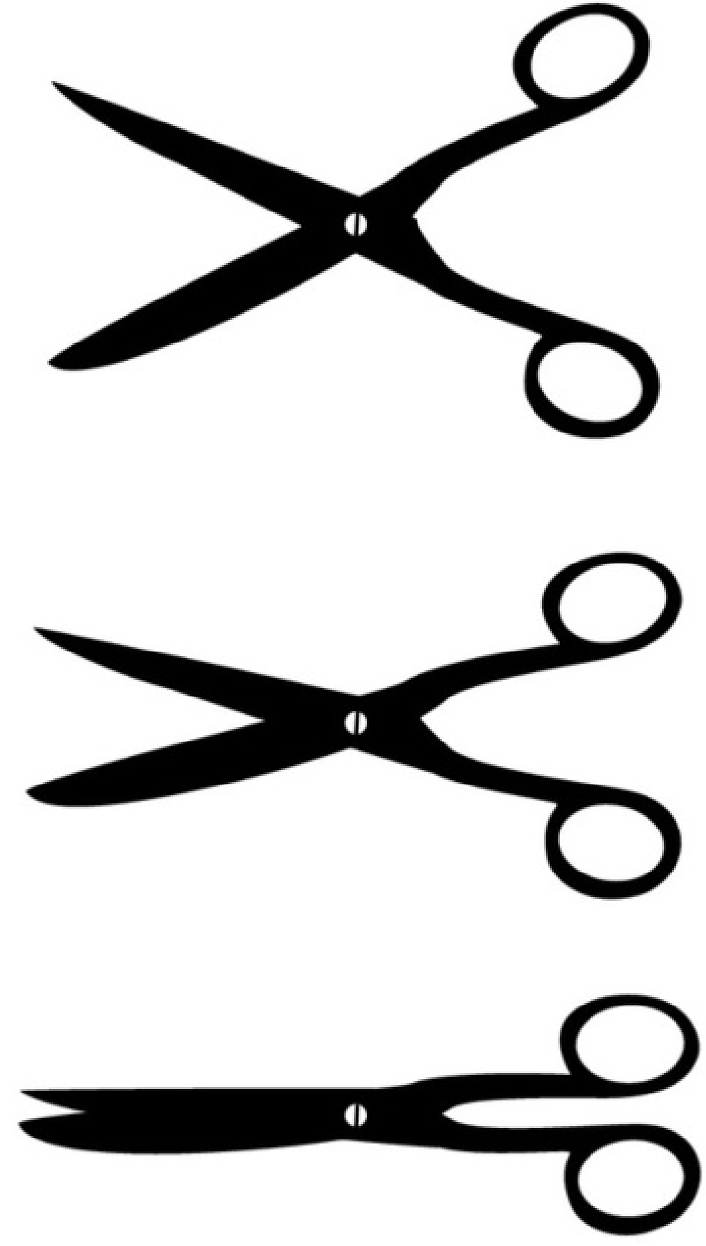
Scissors



Avalanche (RRR)

Bureaucrat (PPP)

Edward's Gambit (SSS)



Crescendo (PSR), Decrescendo (RSP)

Scrapbook (PSP)

Fistful of Dollars (RPP)

Cycle structure and pattern avoidance of *abc*-permutations

Sally Wolfe

July 30, 2010

abc-permutations

Definition

Let *abc*-permutations be elements of S_n obtained by partitioning $[n]$ into three blocks of length a, b, c and exchanging the first and last blocks.

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Examples

[67851234]
[67812345]

Work of Pak and Redlich

In 2008, Pak and Redlich investigated the probability that an *abc*-permutation of length n is a single n-cycle in order to answer a question posed by V. I. Arnold.

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Theorem (Pak-Redlich, 2008)

Let σ_{abc} be an abc-permutation. Then σ_{abc} is a long cycle if and only if

$$\gcd(a + b, b + c) = 1.$$

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Theorem (Pak-Redlich, 2008)

Let $\mathbf{p}(n)$ be the probability that an abc-permutation of length n is a long cycle. Then

$$\lim_{n\to\infty} \mathbf{p}(n) = \frac{6}{\pi^2}.$$

Cycle structure of *abc*-permutations

We fully characterize the cycle structure of *abc*-permutations.

Cycle structure of *abc*-permutations

We fully characterize the cycle structure of *abc*-permutations.

Theorem

Let $k = \gcd(a+b, b+c)$. Then σ_{abc} is composed of k cycles of lengths $\lfloor \frac{n}{k} \rfloor$ and $\lceil \frac{n}{k} \rceil$. These cycles correspond to the residue classes of n modulo k.

Cycle structure statistics of *abc*-permutations

We investigate the probability $\mathbf{p}_k(n)$ that a random *abc*-permutation of length n has exactly k cycles.

Theorem

We have

$$\lim_{n\to\infty} \mathbf{p}_k(n) = \frac{1}{k^2}\frac{6}{\pi^2}.$$

Ideas from the classification of cycle structure

First, note that if $x \leq c$, we have

$$\sigma_{abc}(x) = x + a + b.$$

For ease of notation, let $d = c - a$. If $c < x \leq b + c$, we have

$$\sigma_{abc}(x) = x - d,$$

and if $x > b + c$, we have

$$\sigma_{abc}(x) = x - a - b.$$

Ideas from the classification of cycle structure, cont

Therefore, for all i and x we have

$$\sigma^i_{abc}(x) = x + m(a+b) - ld.$$

for some integers m, l satisfying $|m| + |l| \leq i$.

Ideas from the classification of cycle structure, cont

Therefore, for all i and x we have

$$\sigma^i_{abc}(x) = x + m(a+b) - ld.$$

for some integers m, l satisfying $|m| + |l| \leq i$.

Let $k = \gcd(a+b, d) = \gcd(a+b, b+c)$. Then the orbit of x under σ_{abc} will stay within one residue class modulo k.

Ideas from the classification of cycle structure, cont

To show that each residue class contains exactly one residue class, we note that if x is in a cycle of length j, then

$$\sigma_{abc}^{j}(x) = x + m(a+b) - ld = x.$$

and $m + l \leq j$.

Ideas from the classification of cycle structure, cont

To show that each residue class contains exactly one residue class, we note that if x is in a cycle of length j, then

$$\sigma^j_{abc}(x) = x + m(a+b) - ld = x.$$

and $m + l \leq j$.
We show that $\lceil \frac{n}{k} \rceil / 2 < j$.

Idea of the construction of $\mathbf{p}_k(n)$

Let A_k be the event that $k|(a+b)$ and $(b+c)$, and let B_k be the event that $(a+b)/k$ and $(b+c)/k$ are relatively prime integers. Then

$$\mathbf{p}_k(n) = Pr(A_k) \cdot Pr(B_k \text{ given } A_k)$$

Idea of the construction of $\mathbf{p}_k(n)$, cont

Let $f(n,k)$ be the probability that $k \mid (a+b)$ and $(b+c)$ for a random *abc*-permutation of length n.

Lemma (Pak-Redlich, 2008)

$$f(n,k) = \begin{cases} \frac{\left(\frac{n}{k}+1\right)\left(\frac{n}{k}+2\right)}{(n+1)(n+2)} & \text{if } k \mid n \\ \frac{\lfloor\frac{n}{k}\rfloor\left(\lfloor\frac{n}{k}\rfloor+1\right)}{n(n+1)} & \text{if } k \nmid n. \end{cases}$$

Idea of the construction of $\mathbf{p}_k(n)$, cont

Then

$$\mathbf{p}_k(n) = f(n,k) \cdot Pr(B_k \text{ given } A_k).$$

Idea of the construction of $\mathbf{p}_k(n)$, cont

Then

$$\mathbf{p}_k(n) = f(n,k) \cdot Pr(B_k \text{ given } A_k).$$

If $n \mid k$, we have that $k \mid (a+b)$ and $(b+c)$ implies that $k \mid a, b, c$. Then choosing the blocks a, b, c partitioning n is equivalent to choosing blocks $a/k, b/k, c/k$ partitioning n/k.

Idea of the construction of $\mathbf{p}_k(n)$, cont

Then

$$\mathbf{p}_k(n) = f(n,k) \cdot Pr(B_k \text{ given } A_k).$$

If $n \mid k$, we have that $k \mid (a+b)$ and $(b+c)$ implies that $k \mid a, b, c$. Then choosing the blocks a, b, c partitioning n is equivalent to choosing blocks $a/k, b/k, c/k$ partitioning n/k.

Then $Pr(B_k \text{ given } A_k) = \mathbf{p}(n/k)$, so

$$\mathbf{p}_k(n) = f(n,k)\mathbf{p}(n/k).$$

Definition of $\mathbf{p}_k(n)$

Since

$$\mathbf{p}(n) = 1 - \sum_{s=2}^{n} \mu(s) f(n,s),$$

we have

Definition of $\mathbf{p}_k(n)$

Since

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we have

Theorem

$$\mathbf{p}_k(n) = \begin{cases} f(n,k)(1 - \sum_{s=2}^{n/k} \mu(s) f(n/k, s)) & \text{if } n \mid k \\ f(n,k)(1 - \sum_{s=2}^{n/k} \mu(s) \Gamma(n/k, s)) & \text{if } n \nmid k \end{cases}$$

where $\Gamma(n,k)$ *is a similar function to* $f(n,k)$*.*

Limit of $\mathbf{p}_k(n)$

Theorem

We have

$$\lim_{n\to\infty} \mathbf{p}_k(n) = \frac{1}{k^2}\frac{6}{\pi^2}.$$

Pattern avoidance

Let $\sigma \in S_n$, and $\phi \in S_k$ where $k \leq n$.

Definition

We say that σ contains ϕ if there exists a subsequence of σ which is order isomorphic to ϕ. Otherwise, we say that σ avoids ϕ.

Pattern avoidance and *abc*-permutations

Theorem

The set of abc-permutations is the set of permutations which avoid 132, 213, *and* 4321.

Pattern avoidance and *abc*-permutations

Theorem

The set of abc-permutations is the set of permutations which avoid 132, 213, *and* 4321*.*

In order to prove this theorem we make use of the fact that *abc*-permutations are *reverse layered permutations* with three or fewer layers.

Reverse layered permutations

Definition

A permutation ϕ is called reverse layered if it is of the form $q_1 q_2 \dots q_k$, where the q_i are strings of consecutively increasing numbers and $q_i > q_j$ if $i < j$.

Reverse layered permutations

Definition

A permutation ϕ is called reverse layered if it is of the form $q_1 q_2 \ldots q_k$, where the q_i are strings of consecutively increasing numbers and $q_i > q_j$ if $i < j$.

Lemma (Monsour, 2002)

The set of reverse layered permutations is the set of 132 *and* 213 *avoiding permutations.*

Proof of classification of *abc*-permutations

Assume that σ is reverse layered and avoids 4321. Then it has at most three layers, so it is an *abc*-permutation.

Proof of classification of *abc*-permutations

Assume that σ is reverse layered and avoids 4321. Then it has at most three layers, so it is an *abc*-permutation.

Now assume that σ is an *abc*-permutation. Then it is reverse layered, so it avoids 132, and 213. It also has at most three layers, so it avoids 4321.

Avenues for further research

1. What is the cycle structure of layered permutations?

Avenues for further research

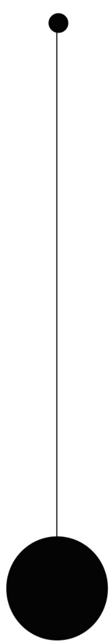
1. What is the cycle structure of layered permutations?
2. What is the structure and number of permutations which avoid 132, 213, and another permutation of length at least four?

Stabilizing unstable systems: balance and levitation

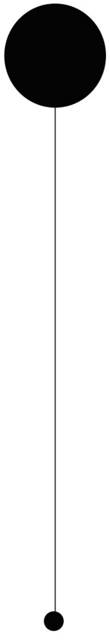
Sally Wolfe

Equilibria

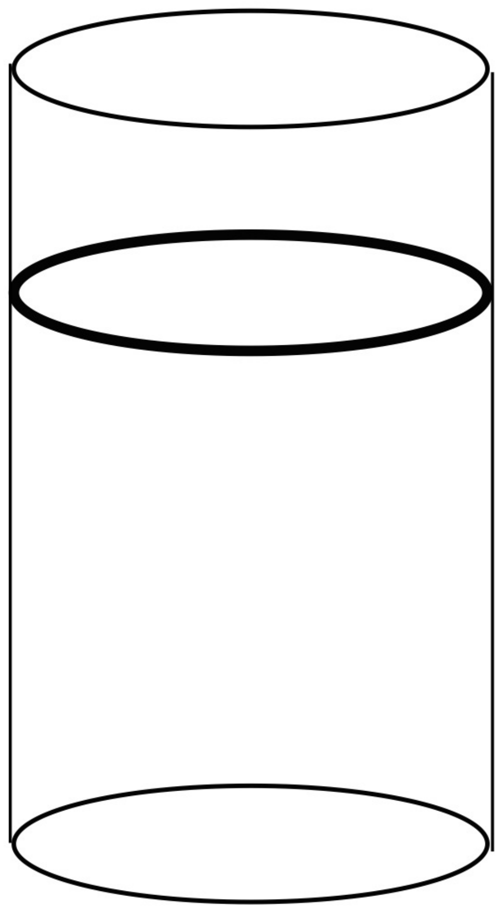
Stable



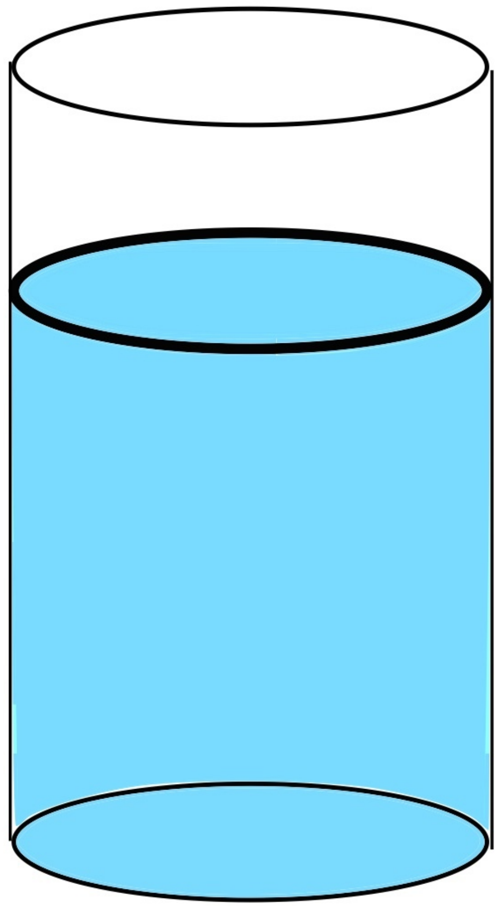
Unstable



Filling a glass to a specific height



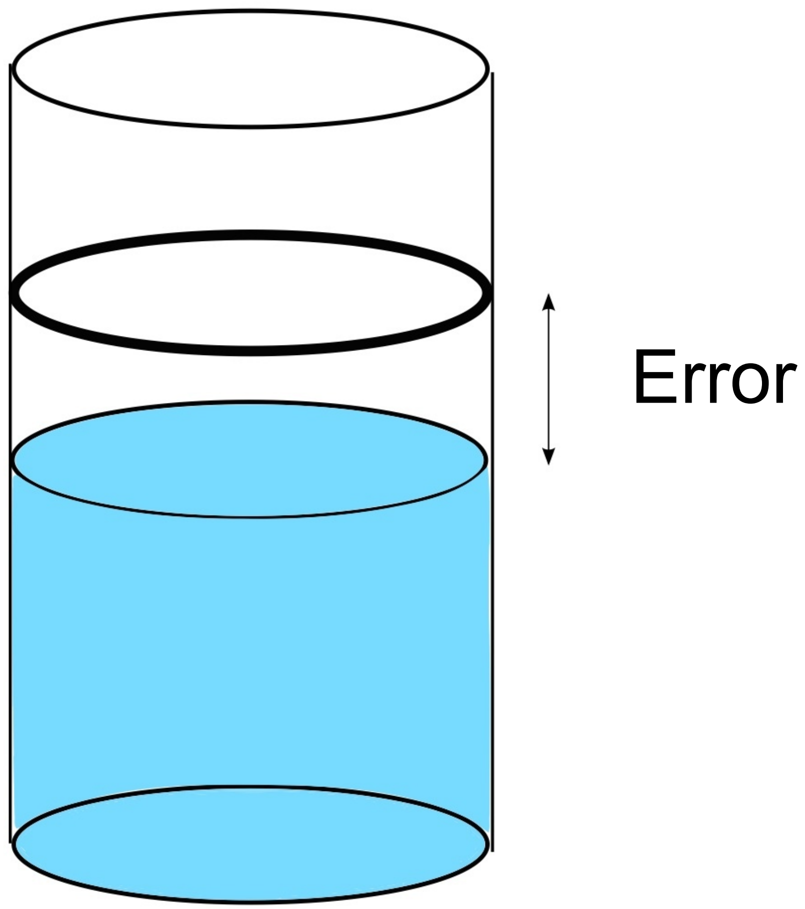
Filling a glass to a specific height



Constant rate of flow

Time = volume/rate of flow

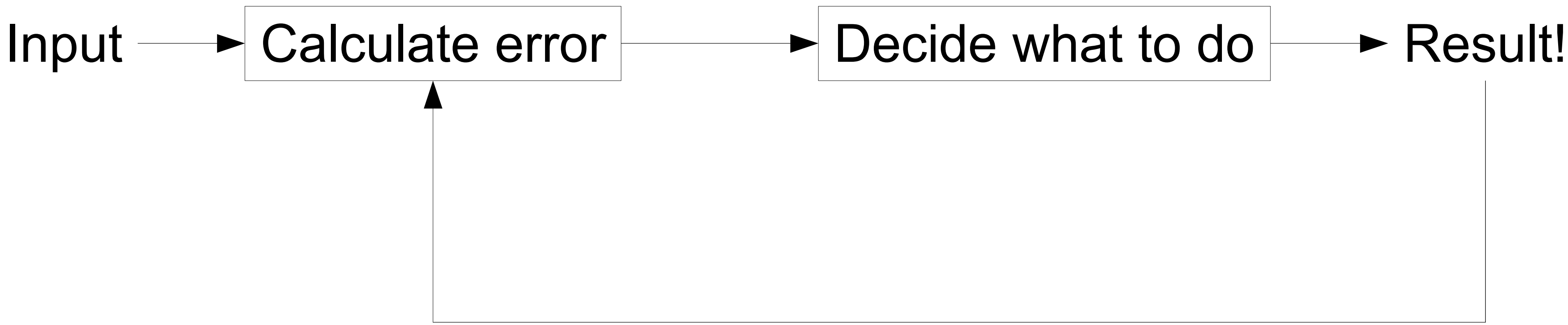
Filling a glass to a specific height



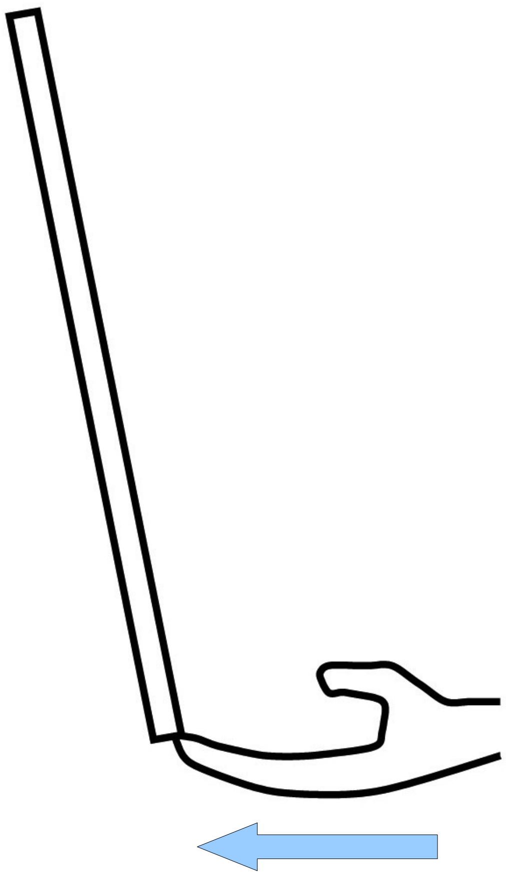
Choosing behavior based on error

- Desired result
- Method of making error measurement
- Way to control the system
- Way of deciding what to do based on error

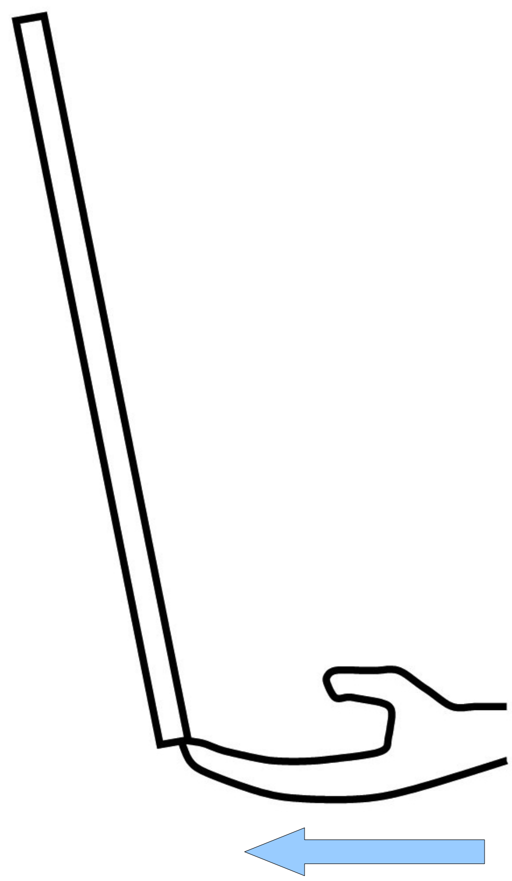
Feedback

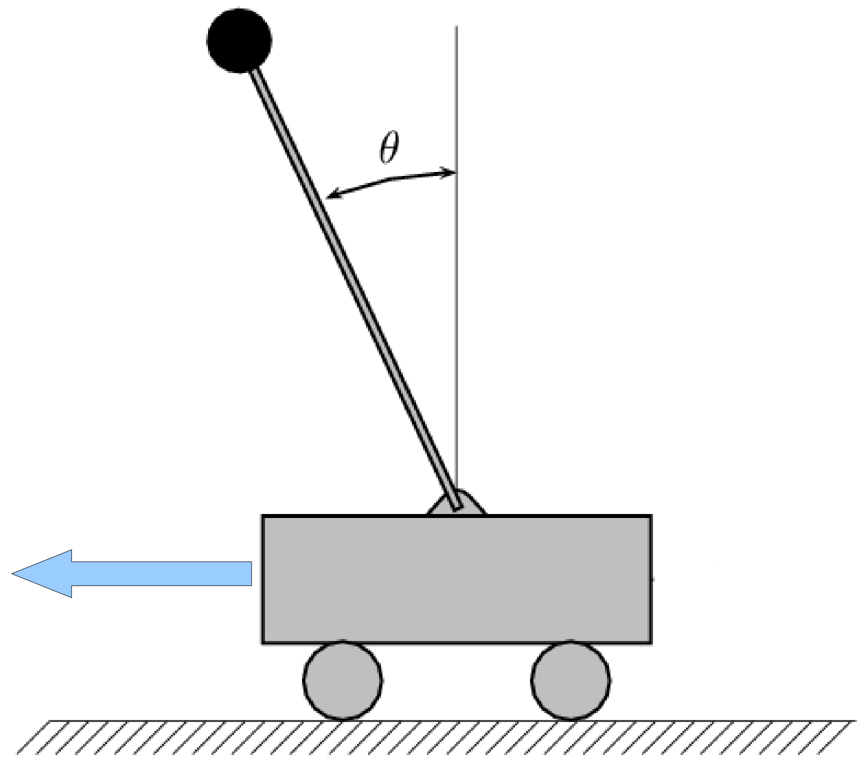


Unstable systems

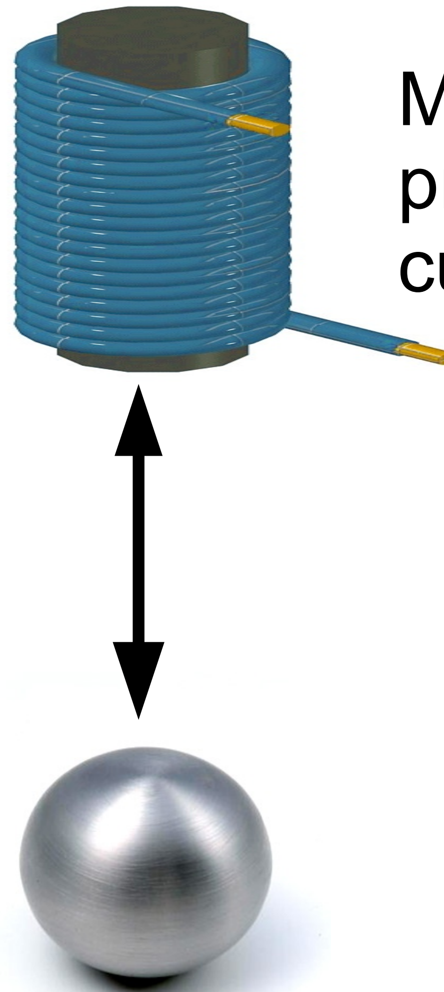


Unstable systems

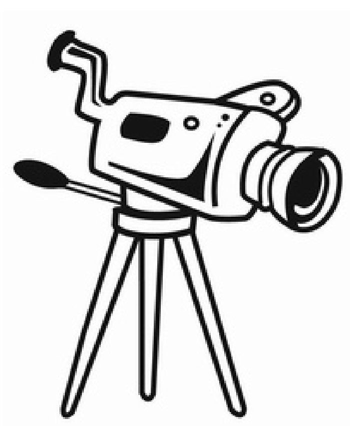




Levitation!

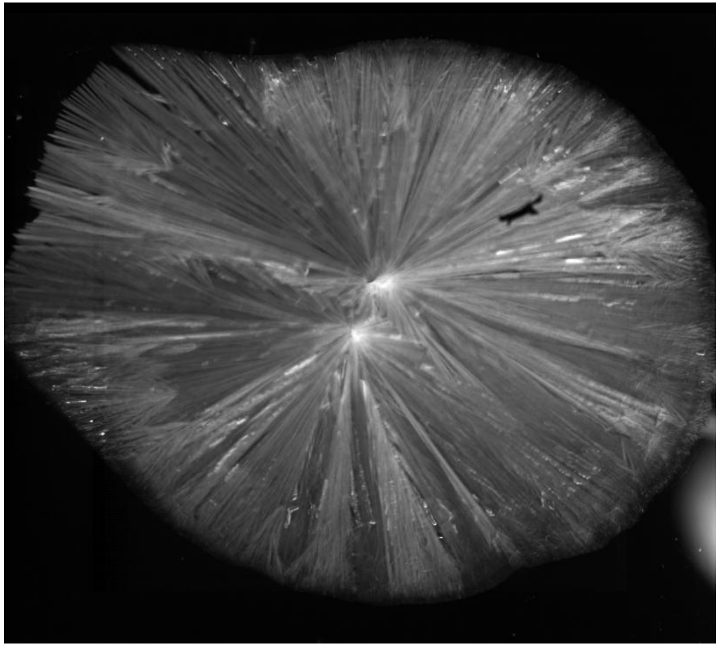


Magnetic field proportional to current



Position sensor

High Speed Crystallization



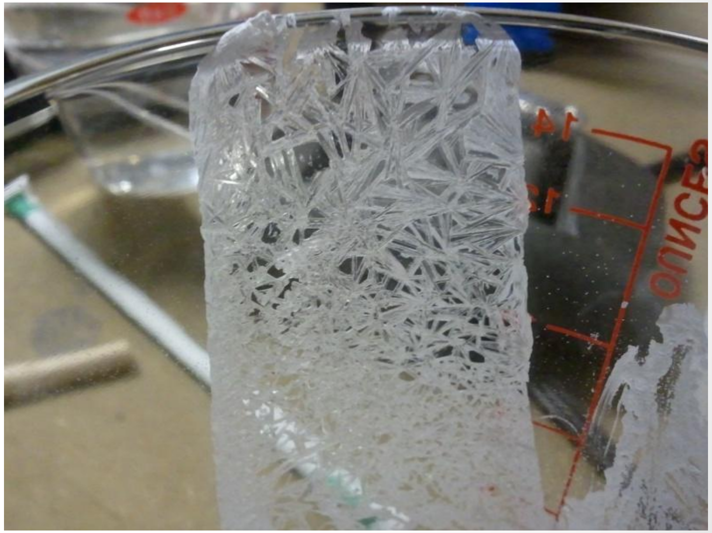
Crystallization of supersaturated Sodium Acetate solution from below. The two points of emanation caused by two seeds are clearly visible. Shot at 1000 fps, f/8, 90mm lens.

Background: crystallization

- Crystallization refers to the formation of solid crystals from a homogeneous solution.
- It is essentially a solid-liquid separation technique and a very important one at that.
- Solubility - Hot liquid dissolves more compounds. Once cooling process starts, compounds become crystals

Background: sodium acetate

- Sodium acetate (NaAc) can perform rapid crystallization when supersaturated
- Supersaturation is when more solute than is normally possible is dissolved into a solvent
    - Can be achieved by increasing temperature
- If a supersaturated solution of NaAc is slowly cooled, it can be rapidly crystallized if perturbed or given a nucleation site



[1] http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA3/MAIN/ACETATE/PAGE1.HTM

Background: bismuth

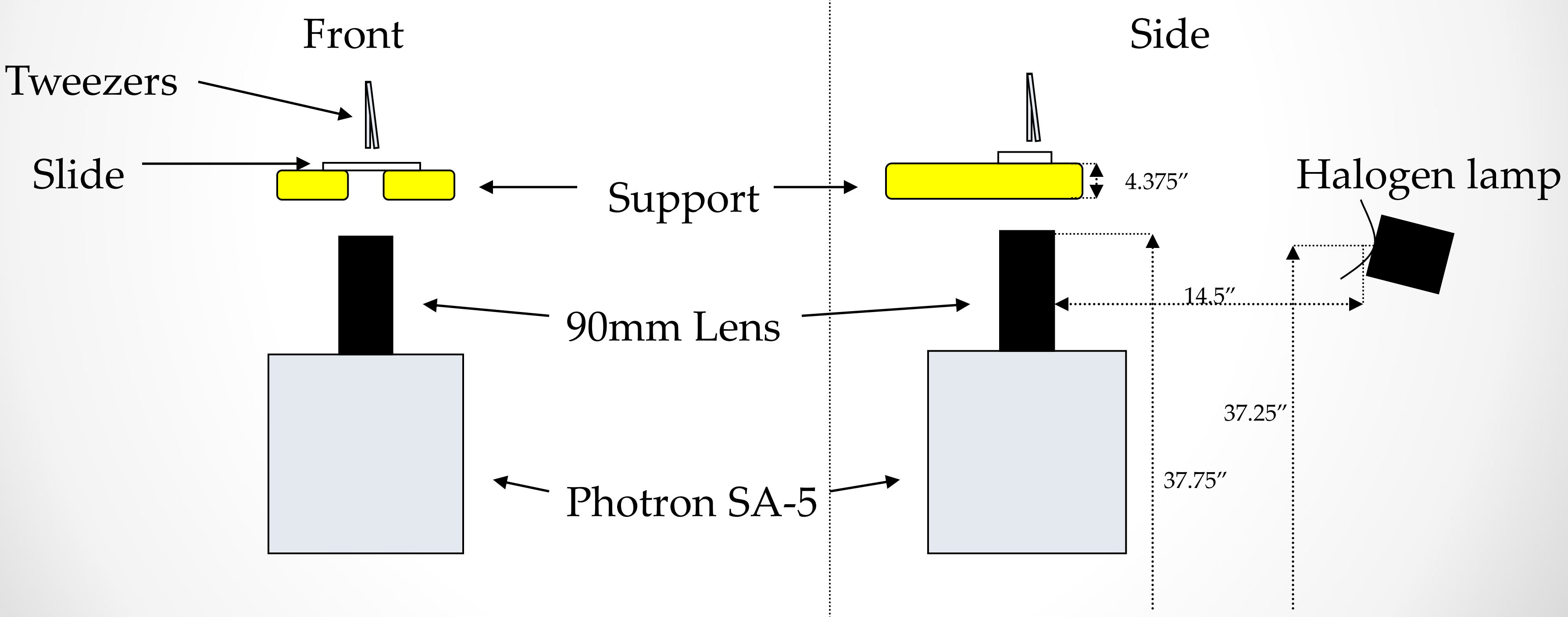
- White/silverish, crystalline, brittle, very dense, highly diamagnetic metallic element
- Very sensitive to high temperatures
- Very viscous and cools rapidly
- Pretty colors and cool shapes

1. http://www.facts-about.org.uk/science-element-bismuth.htm
2. http://upload.wikimedia.org/wikipedia/commons/6/65/Bismuth_Crystal.jpg

Goals:

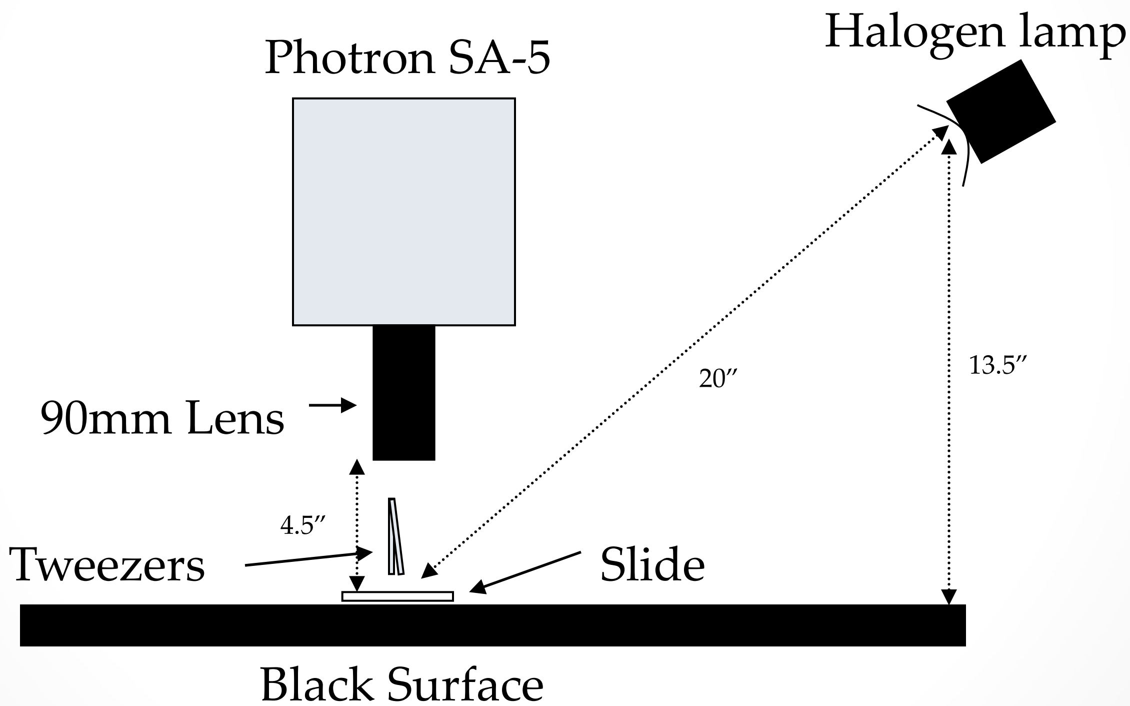
- Observe crystallization process
  - Targets: Sodium Acetate, Bismuth
- Make measurements of speed and process of crystallization
- Determine feasibility of future quantitative studies

Procedure: underneath setup

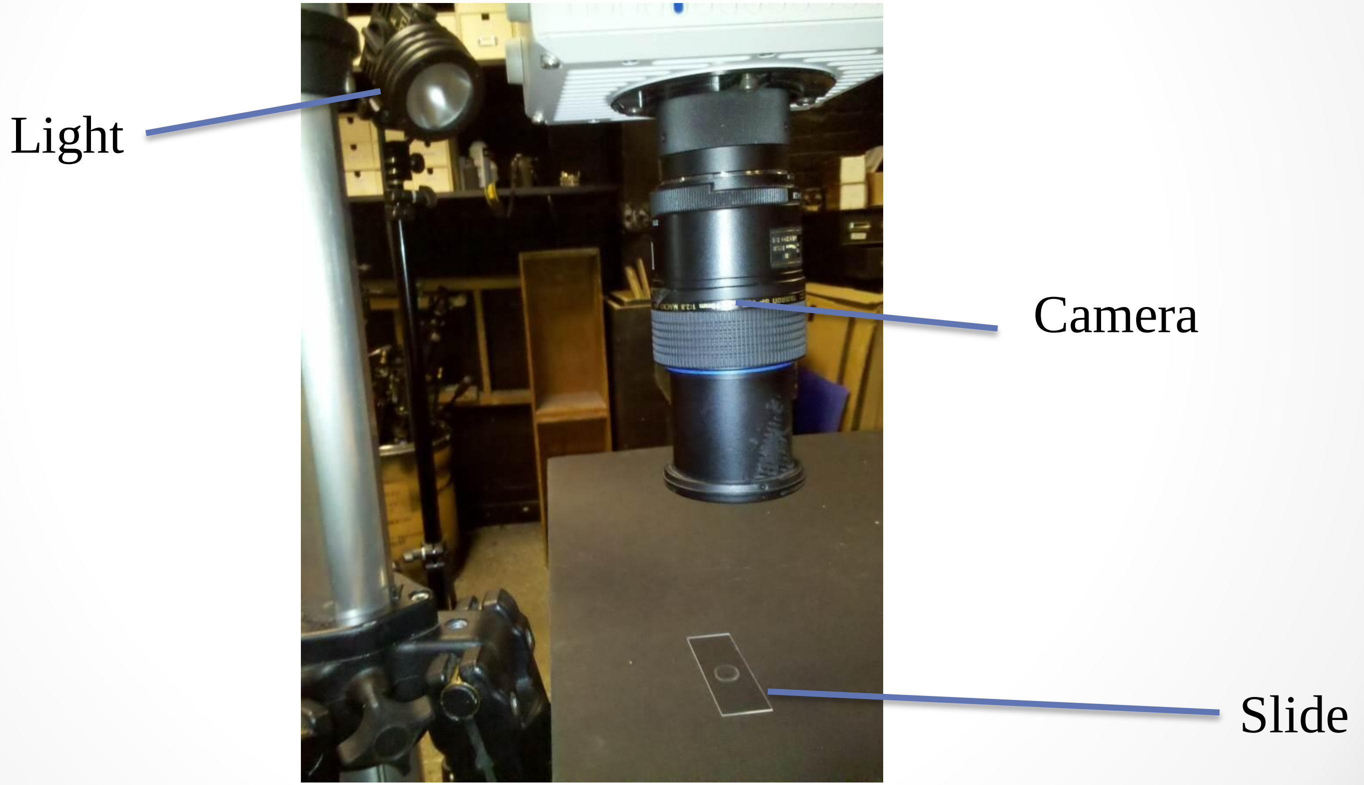


Procedure: underneath setup

Procedure: overhead setup

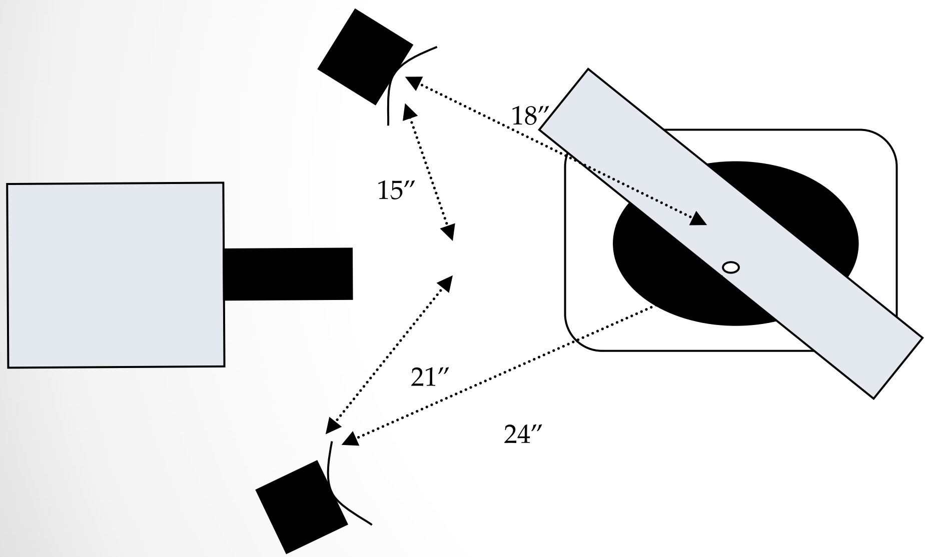


Procedure: overhead setup

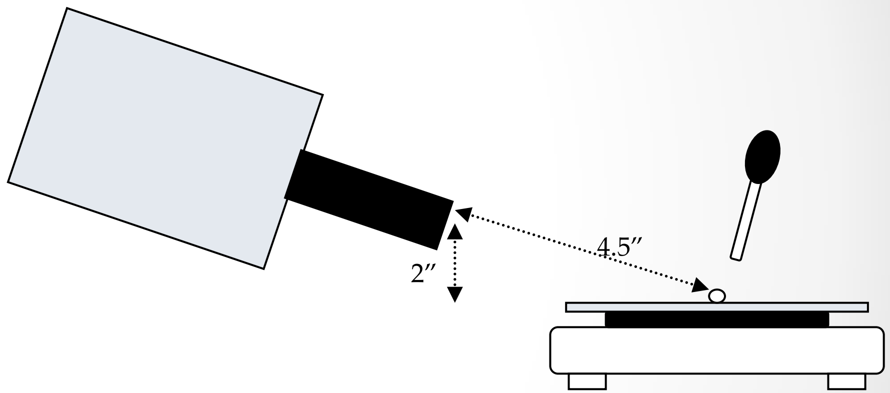


Procedure: boiling setup

Top



Side



Procedure: boiling setup

Light

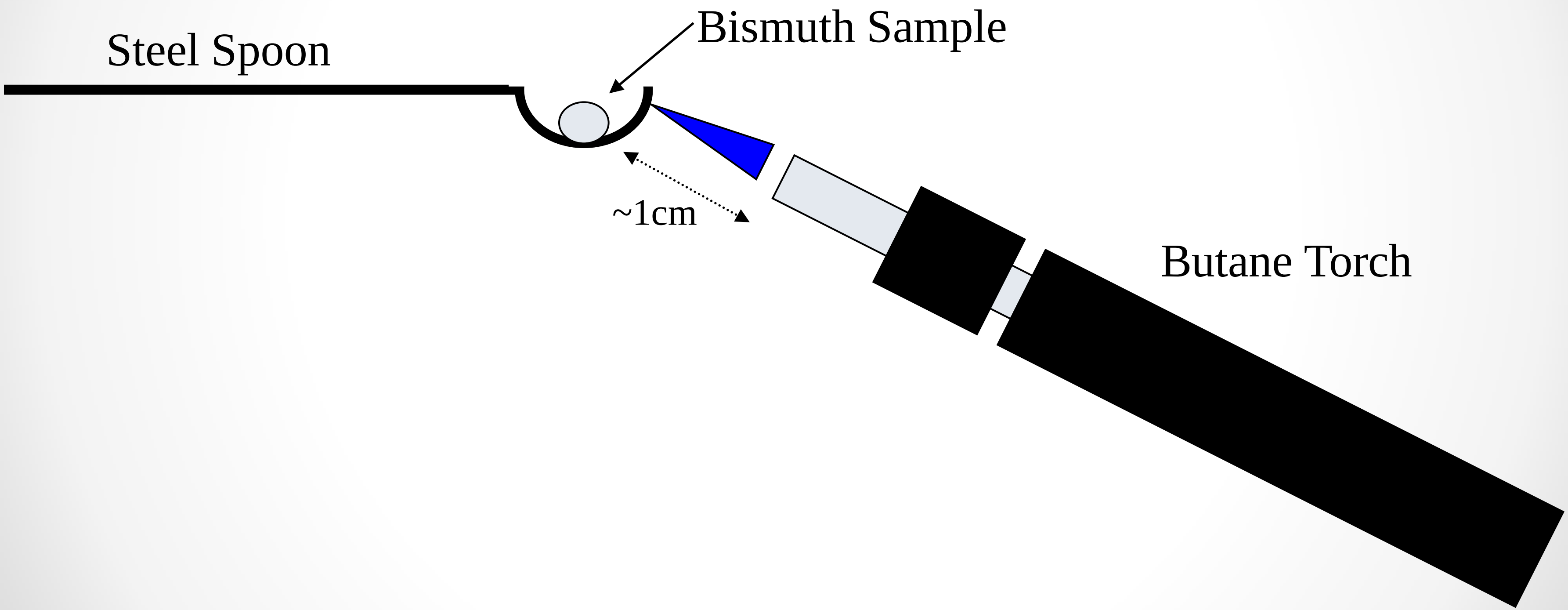
Camera

Hot Plate

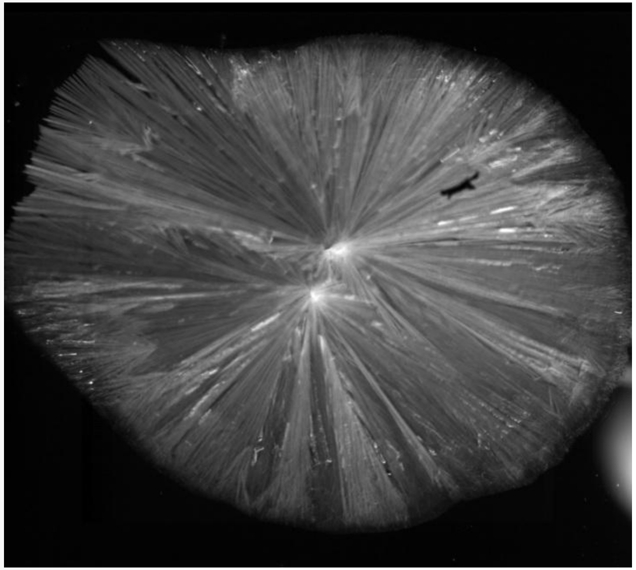
Light

Sheet Metal

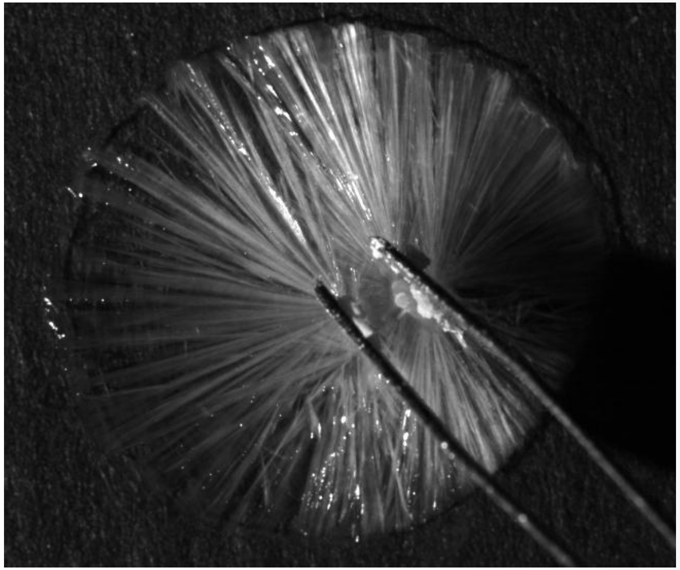
Procedure: bismuth setup



Results

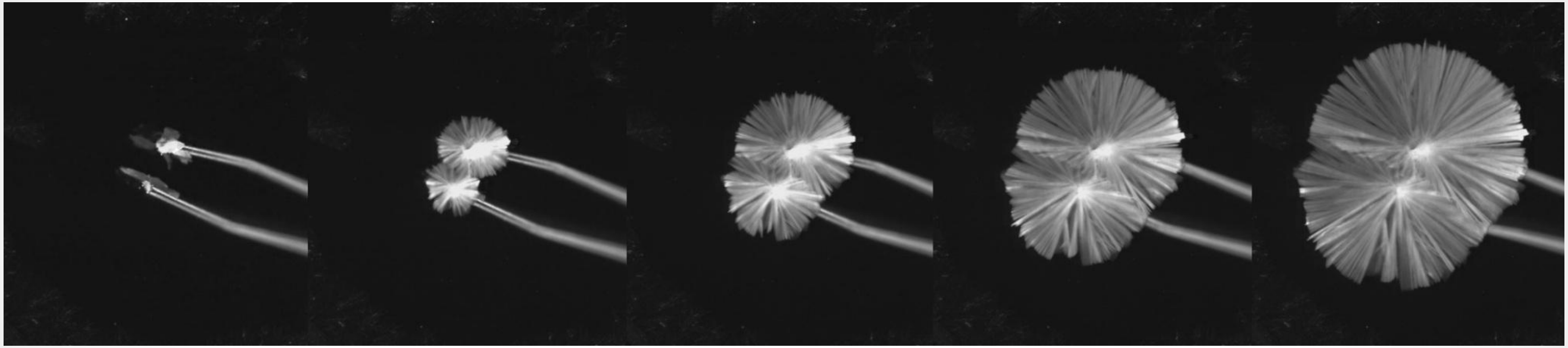


Crystallization of supersaturated Sodium Acetate solution from below. Three drops from an eyedropper. Two points of emanation. Shot at 1000 fps, f/8 90mm lens.



Crystallization of supersaturated Sodium Acetate solution from above. Crystals appear to be on top of the solution. Three drops from an eyedropper. Two points of emanation. Shot at 1000 fps, f/11, 90mm lens. Brightness increased 30% for clarity.

Results



Five frames of Sodium Acetate crystalizing from below. Each frame is .2 seconds apart, all five frames span .8 seconds. Shot at 1000 fps, f/8, 90mm lens.

Results

Close up of solidified bismuth. Color variation from crystal formation is visible. Size is roughly ~3 mm across. f/16, 90mm lens

Results

Solidified bismuth drop. Drop was melted in a spoon then poured onto a slide. The line across the middle of the image is the edge of the slide that the drop landed on. Many colors are visible along the various surfaces. f/36, 90mm lens.

Discussion: summary

Sodium Acetate:

- Crystals form radially outward from seed
- Crystals are long and skinny prisms
- Crystal formation pattern depends on how crystallization is triggered

Bismuth:

- Difficult to form nice looking bismuth crystals
- Colors won’t show up on monochrome high-speed
- No crystal forming process static enough to record

Discussion: conclusions

- Sodium Acetate is feasible
  - Crystallizes consistently and on recordable time scales
- Bismuth isn't feasible
  - Crystallization isn't happening on time/physical scales we have the techniques to record

Discussion: moving forward

With sodium acetate:

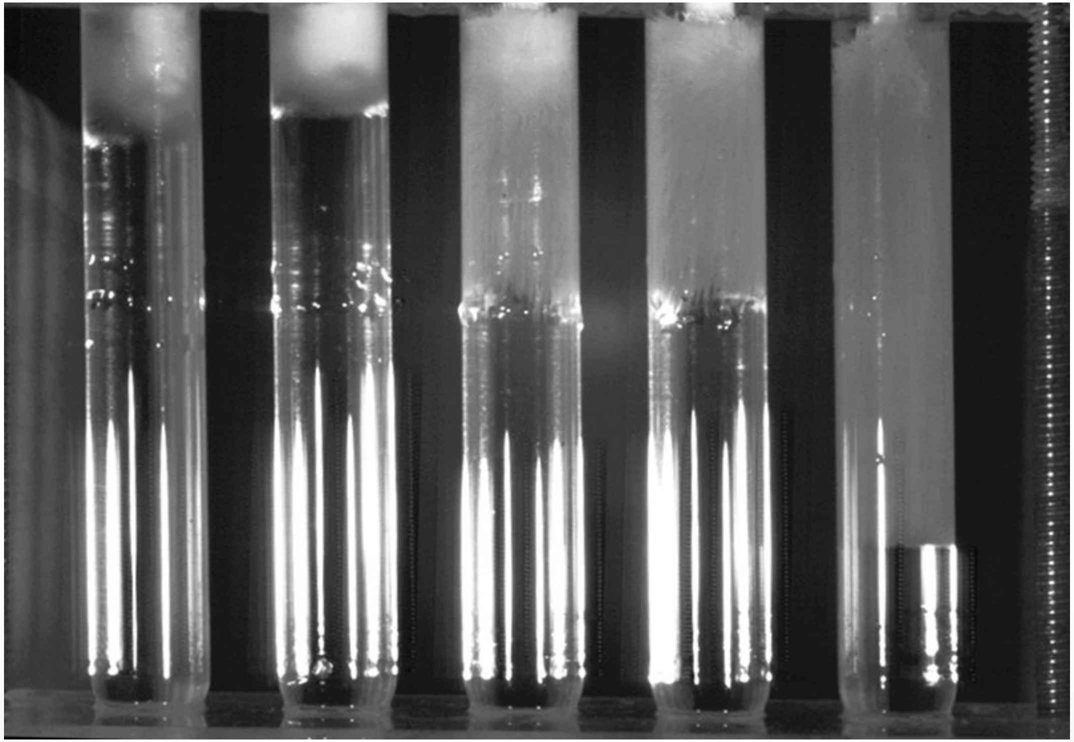
- vary temperature/concentration, look at linear crystallization speed (see 1957 paper)
- look at types/processes of crystallization

Sodium Acetate

Sodium Acetate

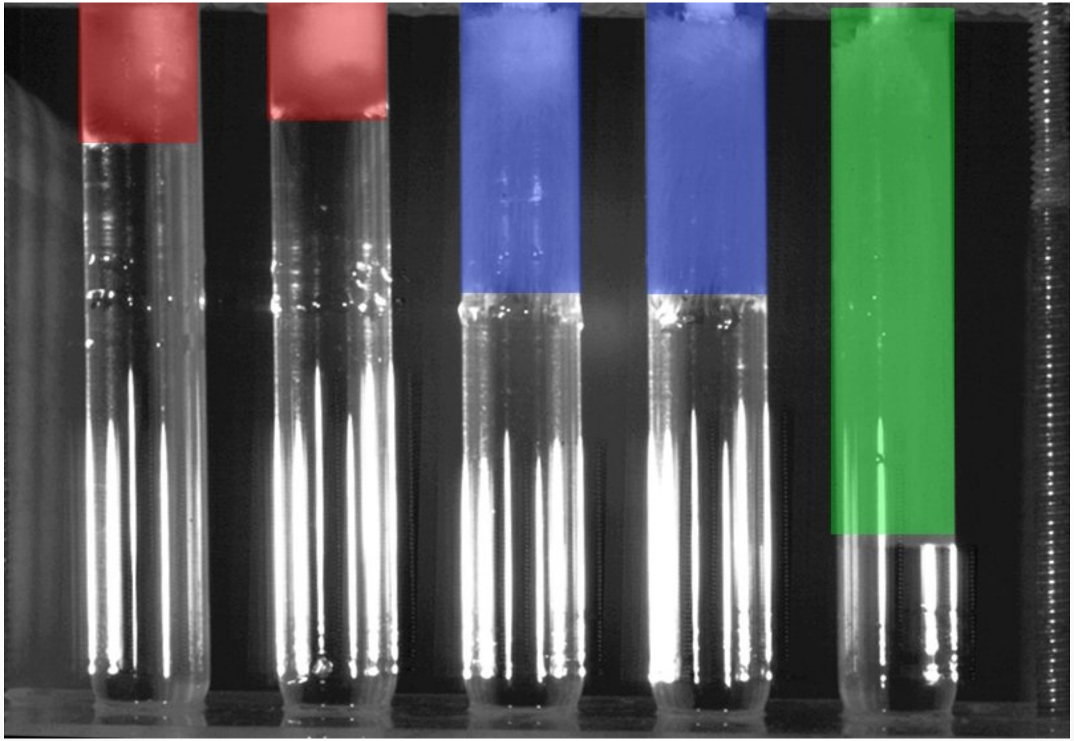
Stable supersaturated solutions crystallize when seed is introduced

High Speed Crystallization of Sodium Acetate



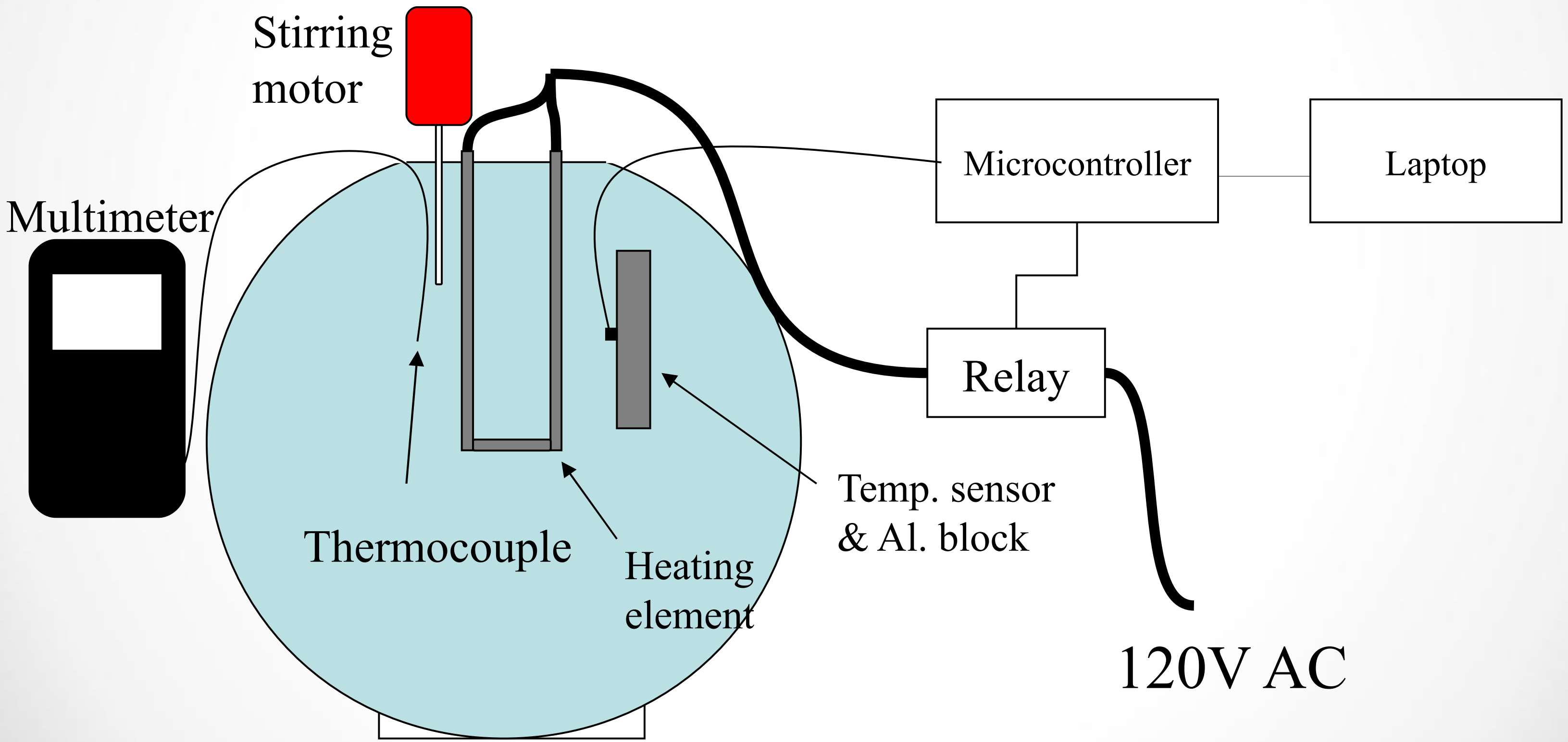
Robin Deits, **Sally Wolfe**, Daniel Ron, Bayo Olatunji

High Speed Crystallization of Sodium Acetate



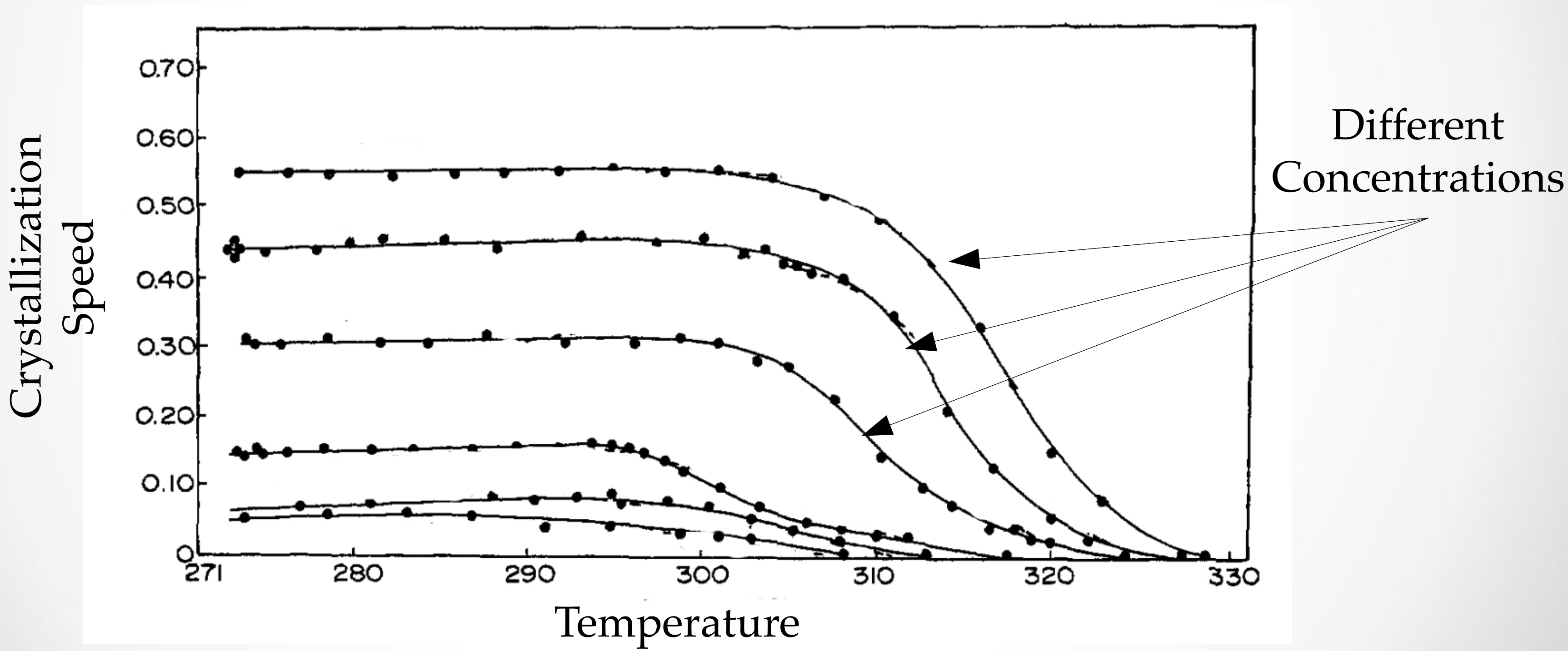
Robin Deits, **Sally Wolfe**, Daniel Ron, Bayo Olatunji

Temperature Regulation



Previous Work

- Dietz, Bruckner, and Hollingsworth (1957)



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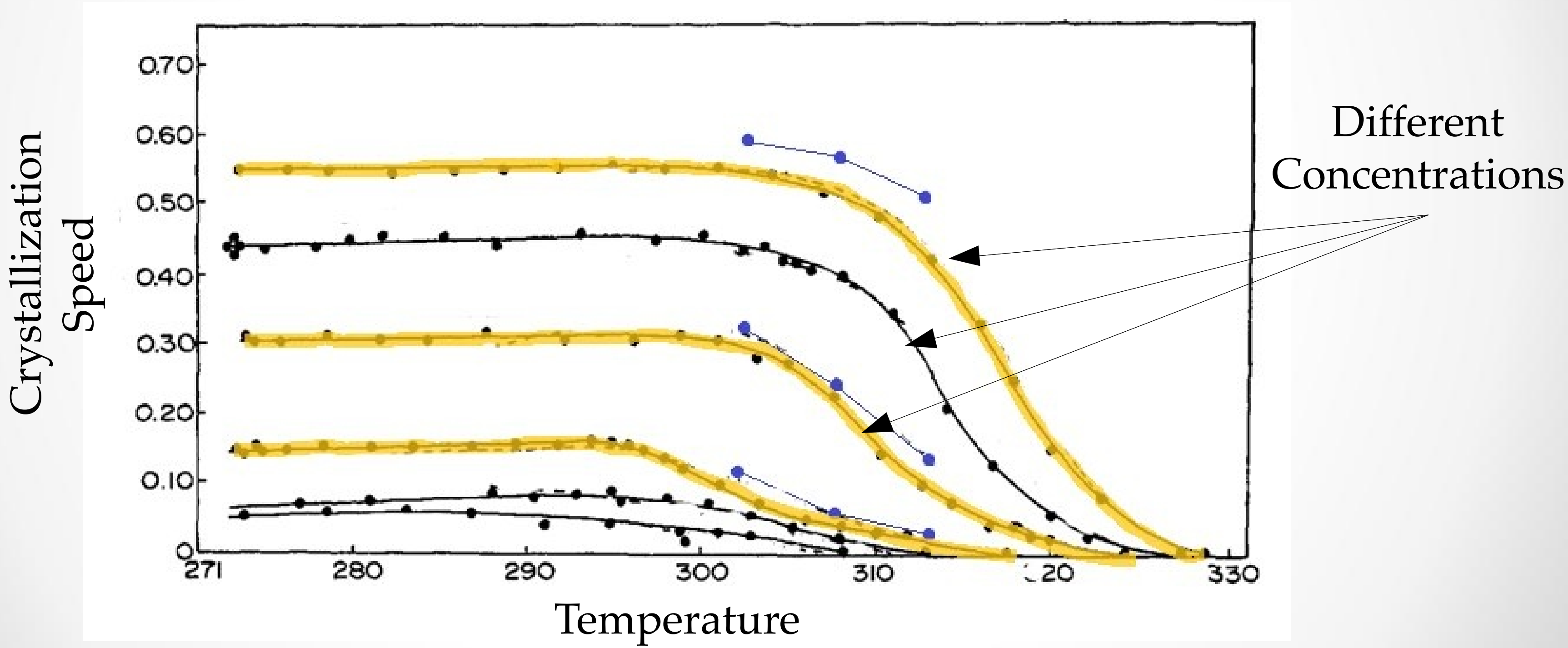


How to Sound Like a Human

(by forgetting your past)

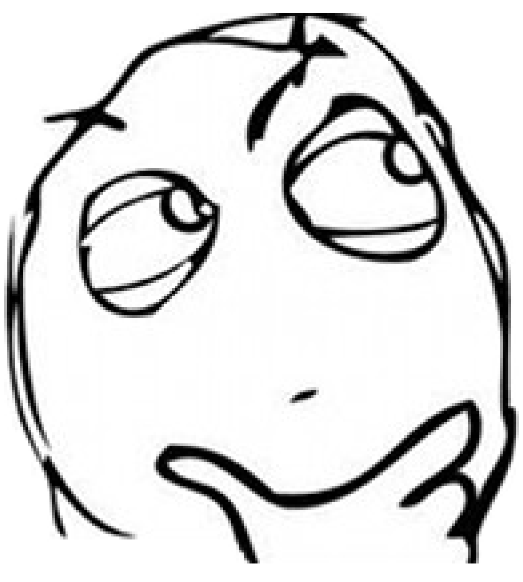
Alan Huang

CHALLENGE ACCEPTED

COMPUTER

Y U NO UNDERSTAND ENGLISH

- Character
- Plot
- Conflict
- Structure
- Setting
- Theme
- Motif
- Style
- Imagery
- Symbolism
- Dialogue
- Perspective



- Words

What comes after what?

Professor…
- McGonagall 28.5%
- Trelawney 8.9%
- Umbridge 8.7%
- Dumbledore 5.9%
- Lupin 5.8%
- Snape 4.6%
- Flitwick 3.9%
- Sprout 3.3%

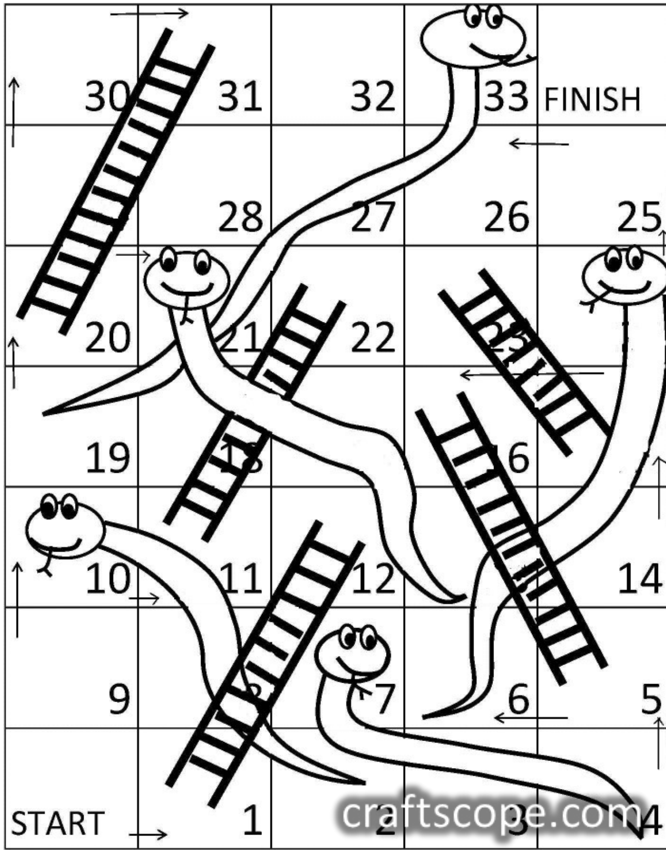
from …
- the 31.1%
- his 6.1%
- a 3.1%
- behind 2.9%
- him 2.5%
- her 2.4%
- under 1.6%
- their 1.6%

Professor Dumbledore knew something extremely odd stuff I’m going to feed the lake and Lies “Isn’t it?”

Markov chain

(the next thing you do depends only on the last few things you did)

(in other words, you *forget* where you were before)



Longer phrases, up to a limit

Professor McGonagall…

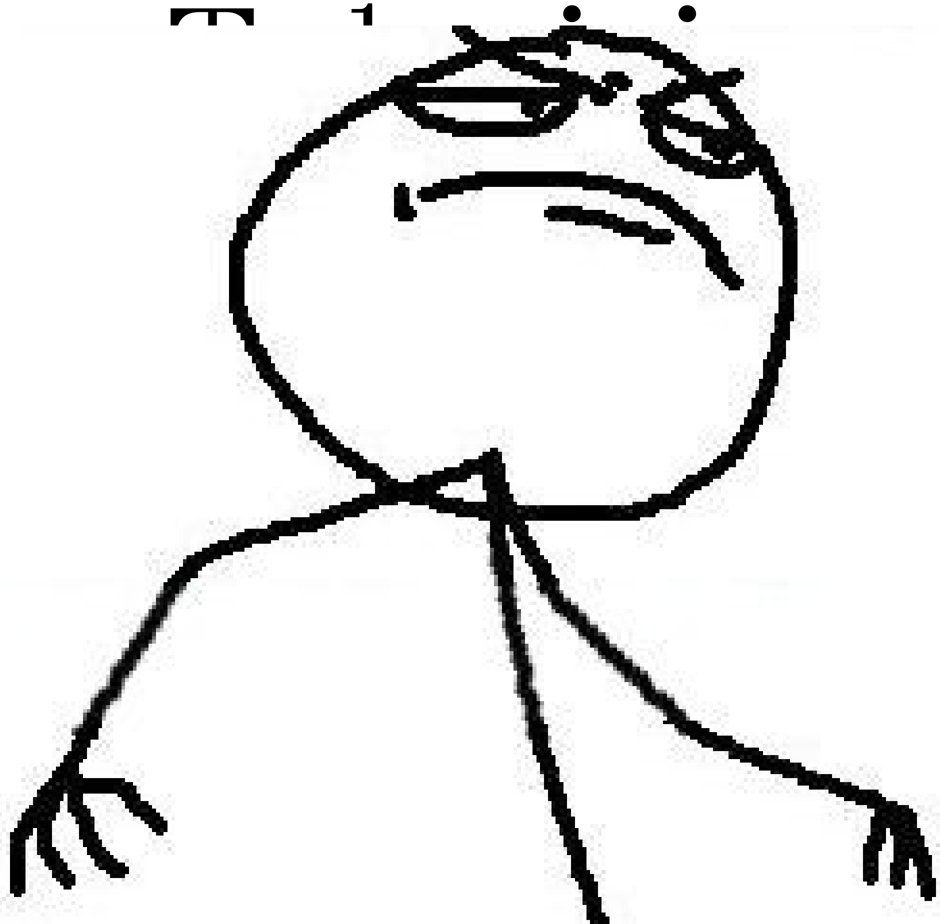
- was 5.5%
- and 4.2%
- had 3.4%
- said 2.7%

McGonagall was…

- now 6.1%
- hurrying 6.1%
- looking 6.1%
- right 6.1%

Professor Flitwick burst into flames and curled up, purring deeply. The common room emptied as people drifted off to bed. he went into the thick black trees.

Harry Potter and the Wide-Screen Television



This is actually useful!

Applications

- Polymer formation
- Cell behavior
- Statistical mechanics
- Financial modeling
- Societal evolution
- Data compression
- Music

Hidden Markov models

- Cryptography
- Error correction
- Speech recognition
- Computer vision
- Machine translation
- Fraud detection
- Pattern recognition

Google PageRank

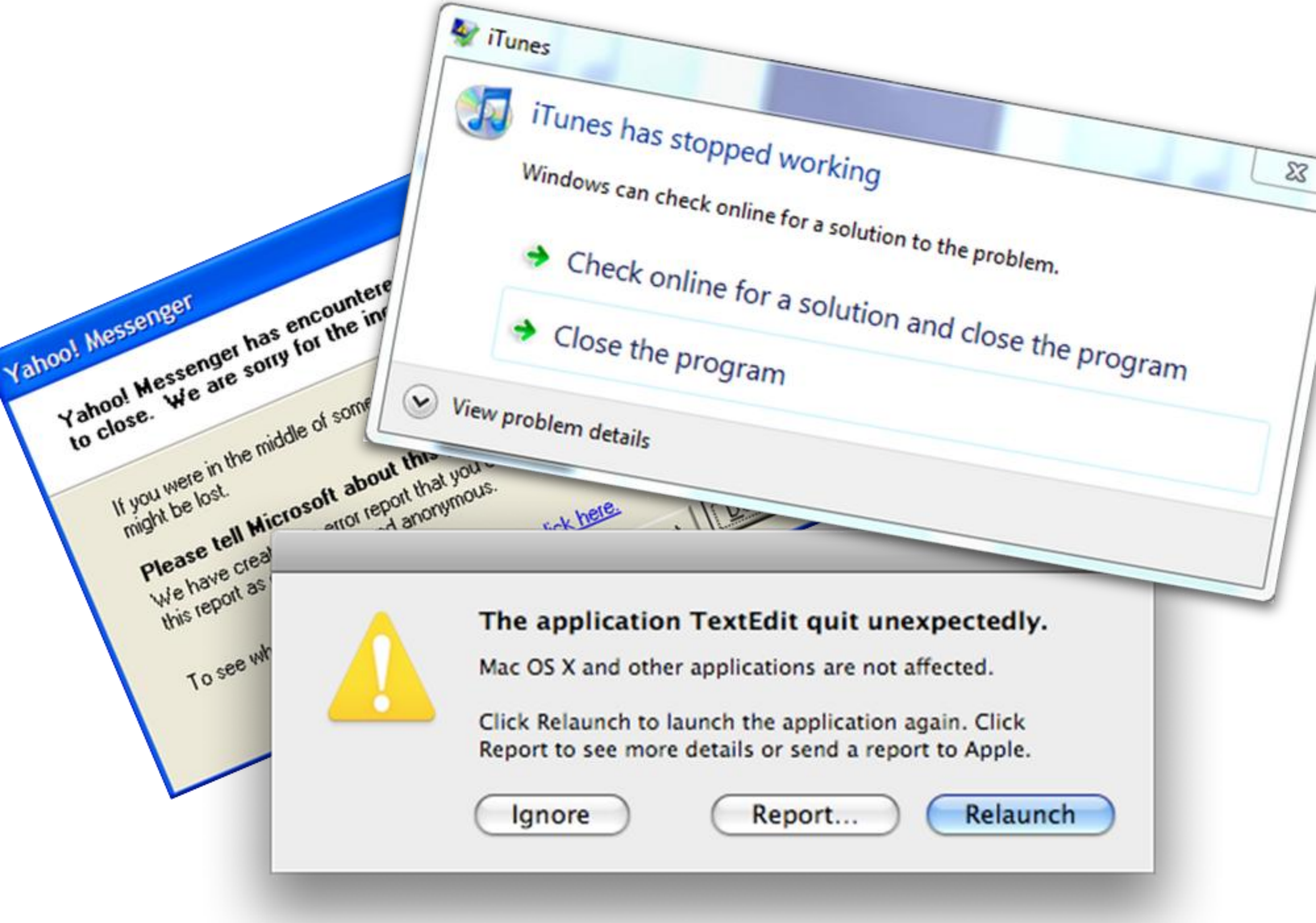
- Internet contains N web pages
- Page contains k links
- Follow a link or type a URL
- Model as a Markov chain
- What pages do users end up on?
- Higher ad prices, earlier search results

Markov chains: *forgetful* models

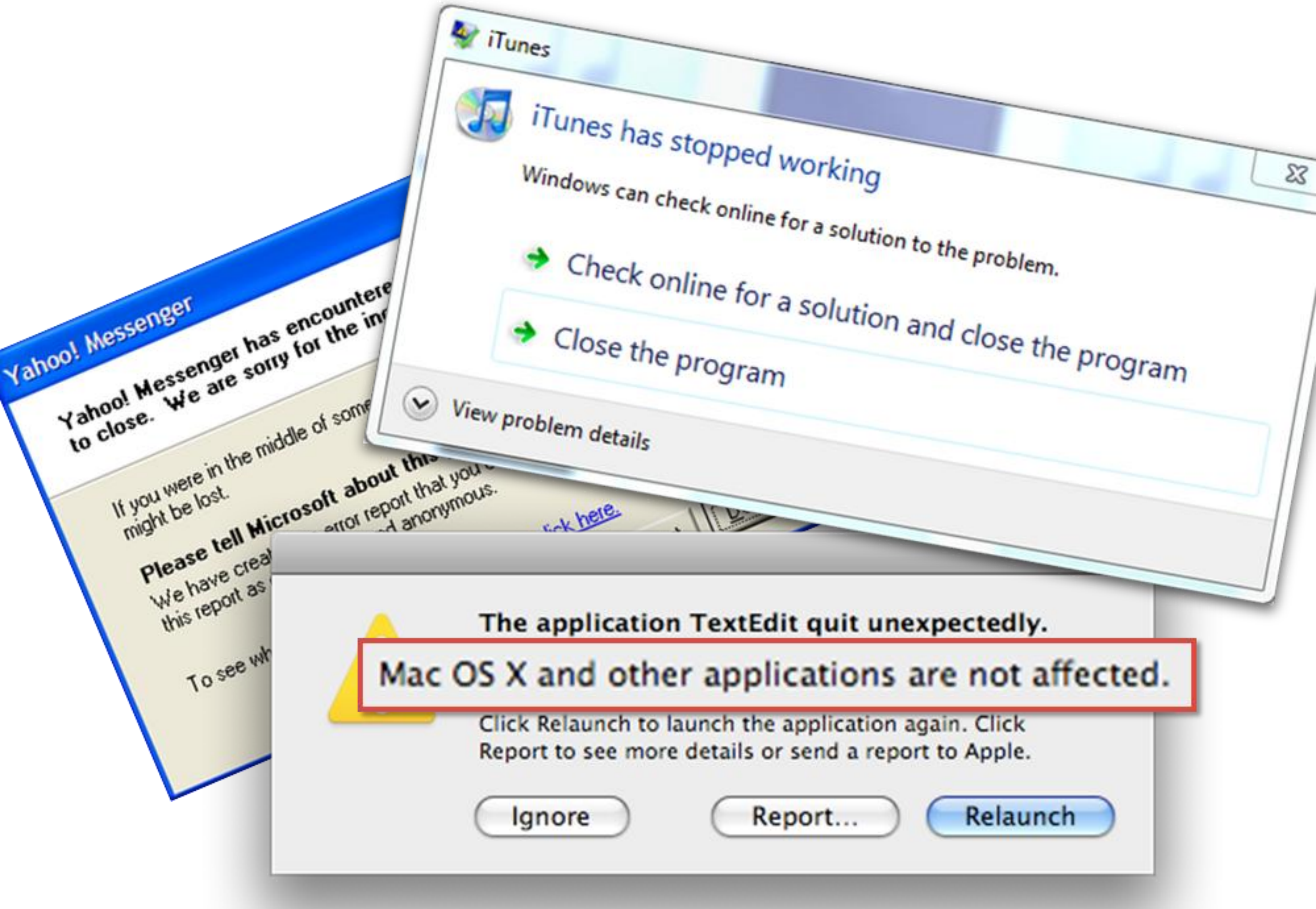
PLAYING IN THE SANDBOX

David Benjamin

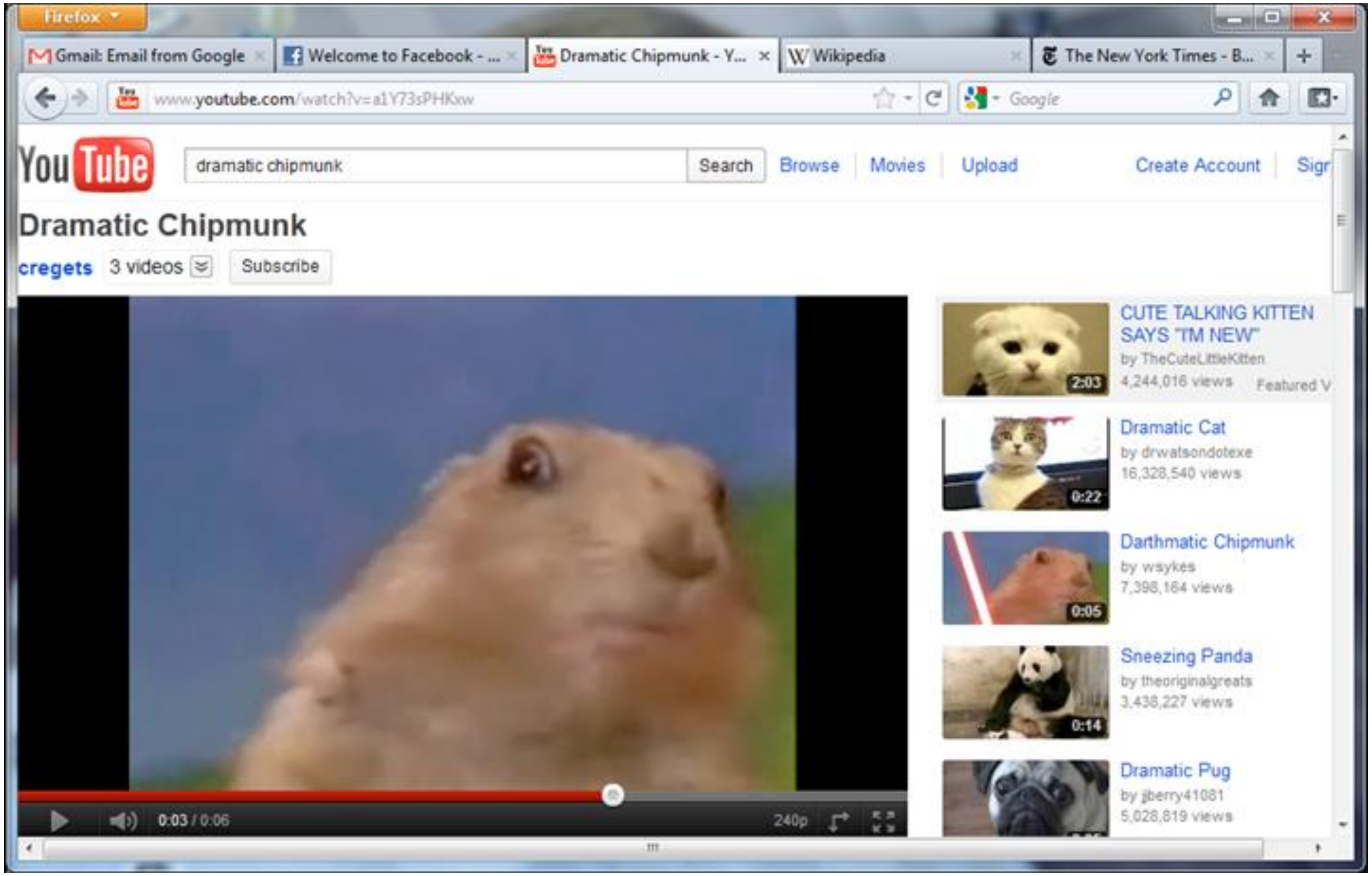
Process Isolation in Google Chrome


Yahoo! Messenger
iTunes
iTunes has stopped working
Windows can check online for a solution to the problem.
Check online for a solution and close the program
Close the program
View problem details
The application TextEdit quit unexpectedly.
Mac OS X and other applications are not affected.
Click Relaunch to launch the application again. Click Report to see more details or send a report to Apple.
Ignore
Report...
Relaunch

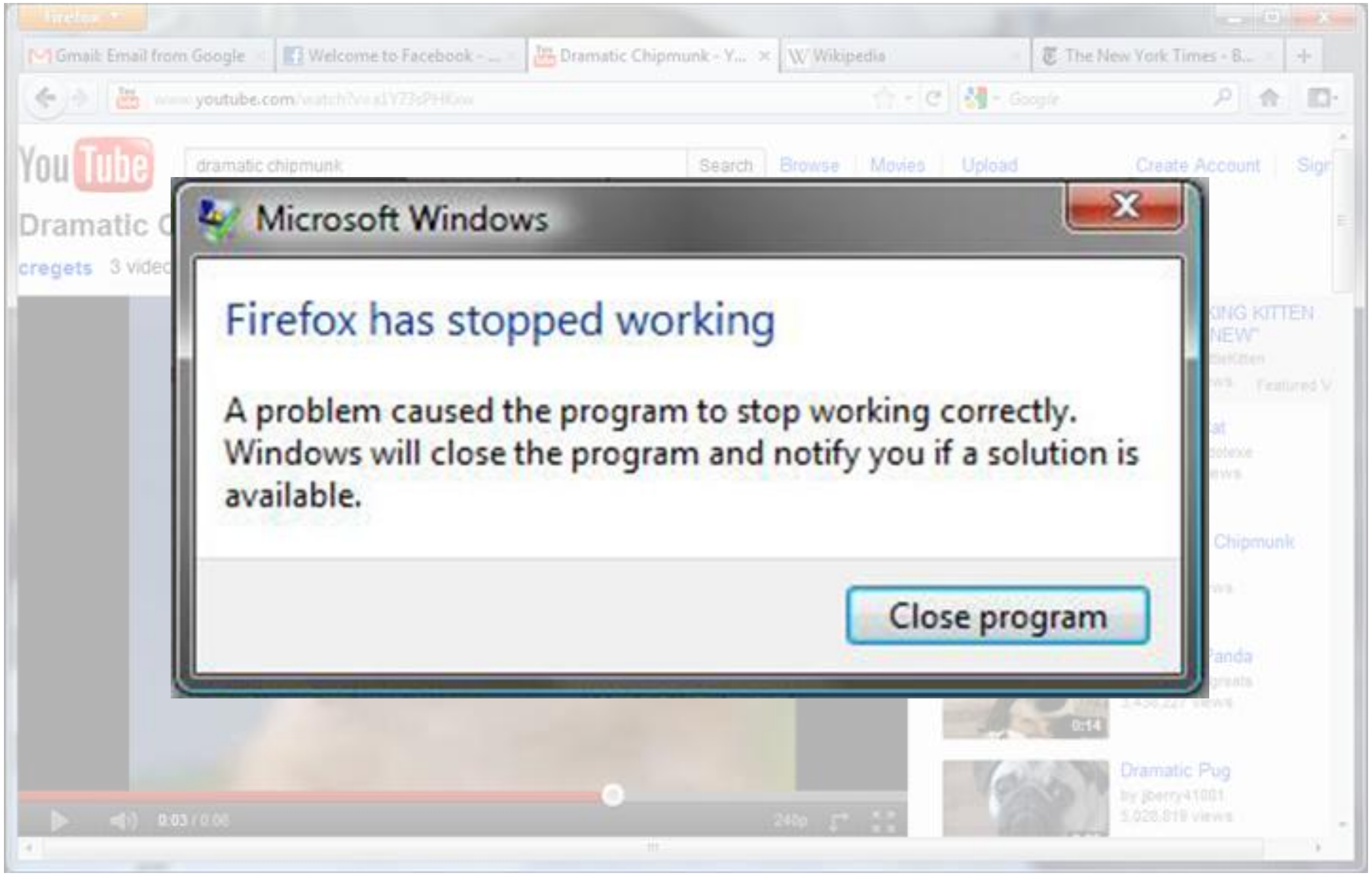
```
*** STOP: 0x00000019 (0x00000000,0xC00E0FF0,0xFFFFEFD4,0xC0000000)
BAD_POOL_HEADER

CPUID:GenuineIntel 5.2.c irql:1f  SYSVER 0xf0000565

Dll Base DateStmp - Name                Dll Base DateStmp - Name
80100000 3202c07e - ntoskrnl.exe        80010000 31ee6c52 - hal.dll
80001000 31ed06b4 - atapi.sys           80006000 31ec6c74 - SCSIPORT.SYS
802c6000 31ed06bf - aic78xx.sys         802cd000 31ed237c - Disk.sys
802d1000 31ec6c7a - CLASS2.SYS          8037c000 31eed0a7 - Ntfs.sys
fc698000 31ec6c7d - Floppy.SYS          fc6a8000 31ec6ca1 - Cdrom.SYS
fc90a000 31ec6df7 - Fs_Rec.SYS          fc9c9000 31ec6c99 - Null.SYS
fc864000 31ed868b - KSecDD.SYS          fc9ca000 31ec6c78 - Beep.SYS
fc6d8000 31ec6c90 - i8042prt.sys        fc86c000 31ec6c97 - mouclass.sys
fc874000 31ec6c94 - kbdclass.sys        fc6f0000 31f50722 - VIDEOPORT.SYS
feffa000 31ec6c62 - mga_mil.sys         fc890000 31ec6c6d - vga.sys
fc708000 31ec6ccb - Msfs.SYS            fc4b0000 31ec6cc7 - Npfs.SYS
fefbc000 31eed262 - NDIS.SYS            a0000000 31f954f7 - win32k.sys
fefa4000 31f91a51 - mga.dll             fec31000 31eedd07 - Fastfat.SYS
feb8c000 31ec6e6c - TDI.SYS             feaf0000 31ed0754 - nbf.sys
feacf000 31f130a7 - tcpip.sys           feab3000 31f50a65 - netbt.sys
fc550000 31601a30 - el59x.sys           fc560000 31f8f864 - afd.sys
fc718000 31ec6e7a - netbios.sys         fc858000 31ec6c9b - Parport.sys
fc870000 31ec6c9b - Parallel.SYS        fc954000 31ec6c9d - ParVdm.SYS
fc5b0000 31ec6cb1 - Serial.SYS          fea4c000 31f5003b - rdr.sys
fea3b000 31f7a1ba - mup.sys             fe9da000 32031abe - srv.sys

Address  dword dump   Build [1381]                            - Name
fec32d84 80143e00 80143e00 80144000 ffdff000 00070b02         - KSecDD.SYS
801471c8 80144000 80144000 ffdff000 c03000b0 00000001         - ntoskrnl.exe
801471dc 80122000 f0003fe0 f030eee0 e133c4b4 e133cd40         - ntoskrnl.exe
80147304 803023f0 0000023c 00000034 00000000 00000000         - ntoskrnl.exe

Restart and set the recovery options in the system control panel
or the /CRASHDEBUG system start option.
```


Yahoo! Messenger
iTunes
iTunes has stopped working
Windows can check online for a solution to the problem.
Check online for a solution and close the program
Close the program
View problem details
The application TextEdit quit unexpectedly.
Mac OS X and other applications are not affected.
Click Relaunch to launch the application again. Click Report to see more details or send a report to Apple.
Ignore
Report...
Relaunch

What if a webpage crashes?

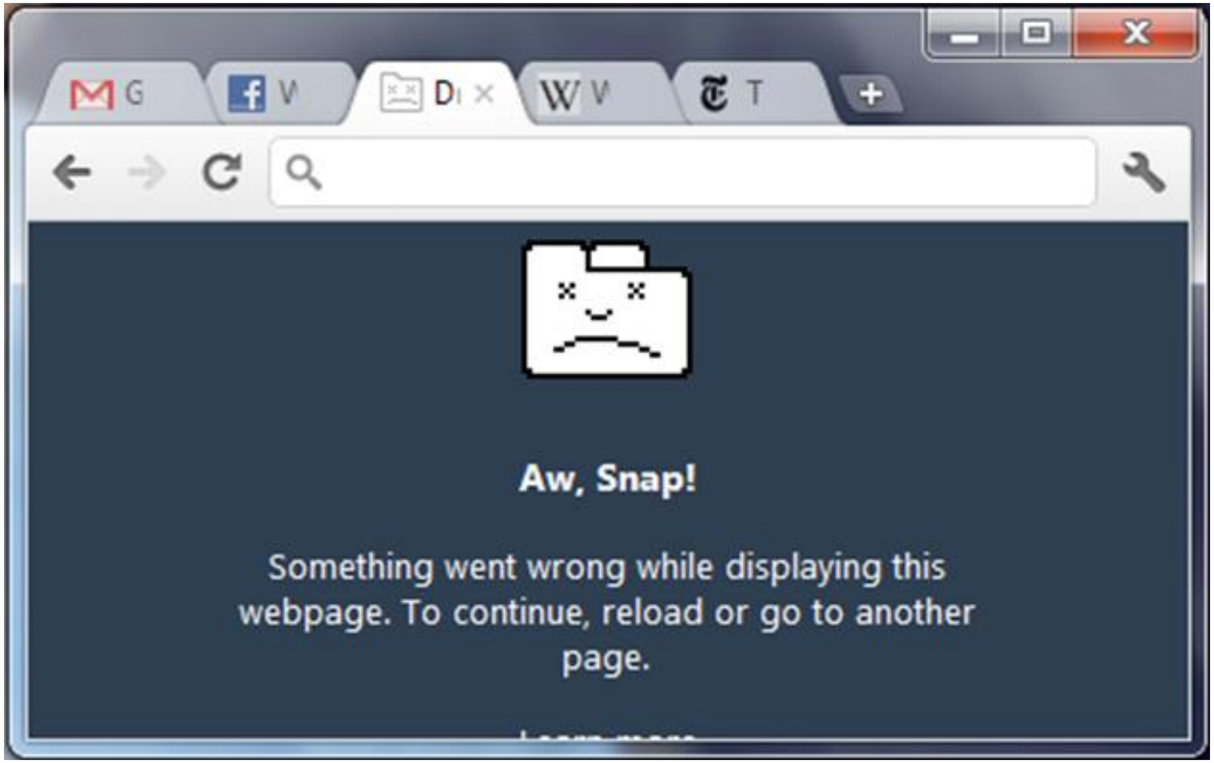


What if a webpage crashes?



Tab isolation

- Chrome brings the same isolation to webpages
- One crashed tab doesn't kill the browser



Why bother?

- Crashes mean browser bugs
- Why not just write correct code?

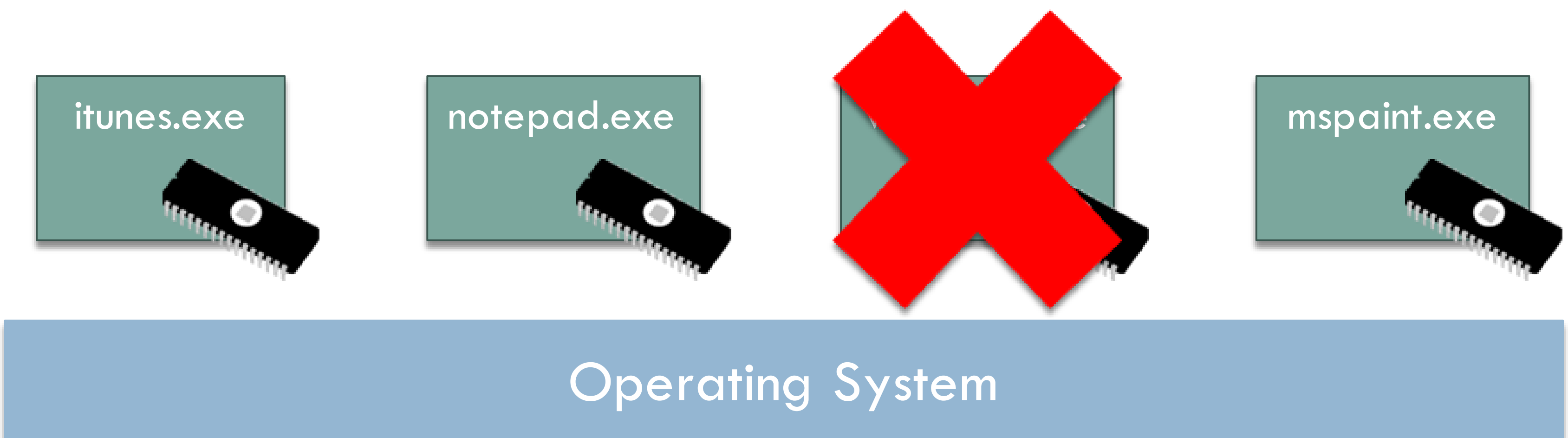
5,000,000

Playing in the sandbox

- How tab isolation works
- Sandboxing
- Principle of least privilege

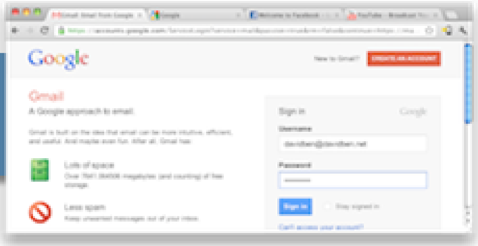
Processes

- Tasks organized into processes
- Typically one process per application
- Each process has private memory, state, etc.
- Independently scheduled and killed

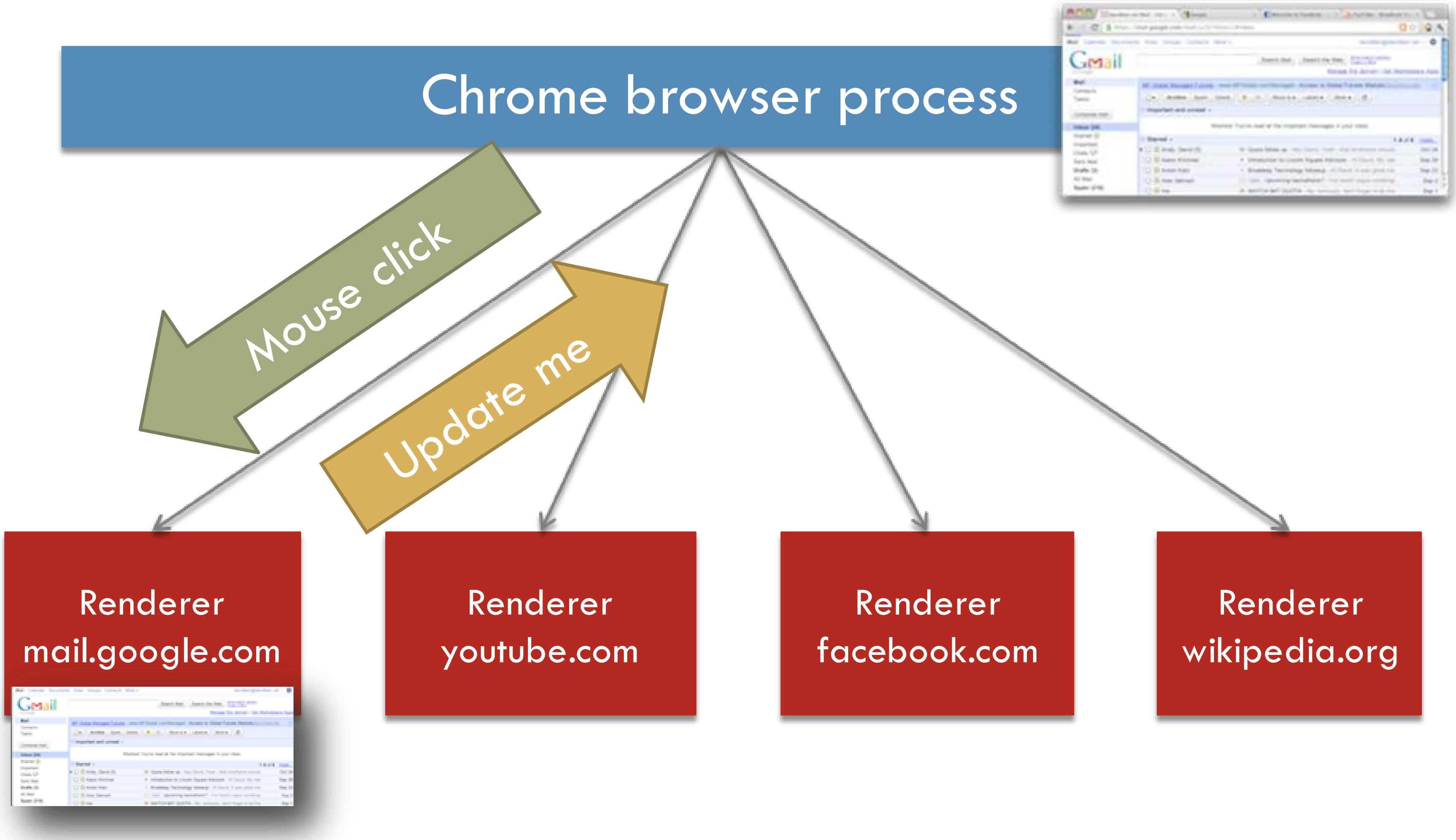


Single-process browsing

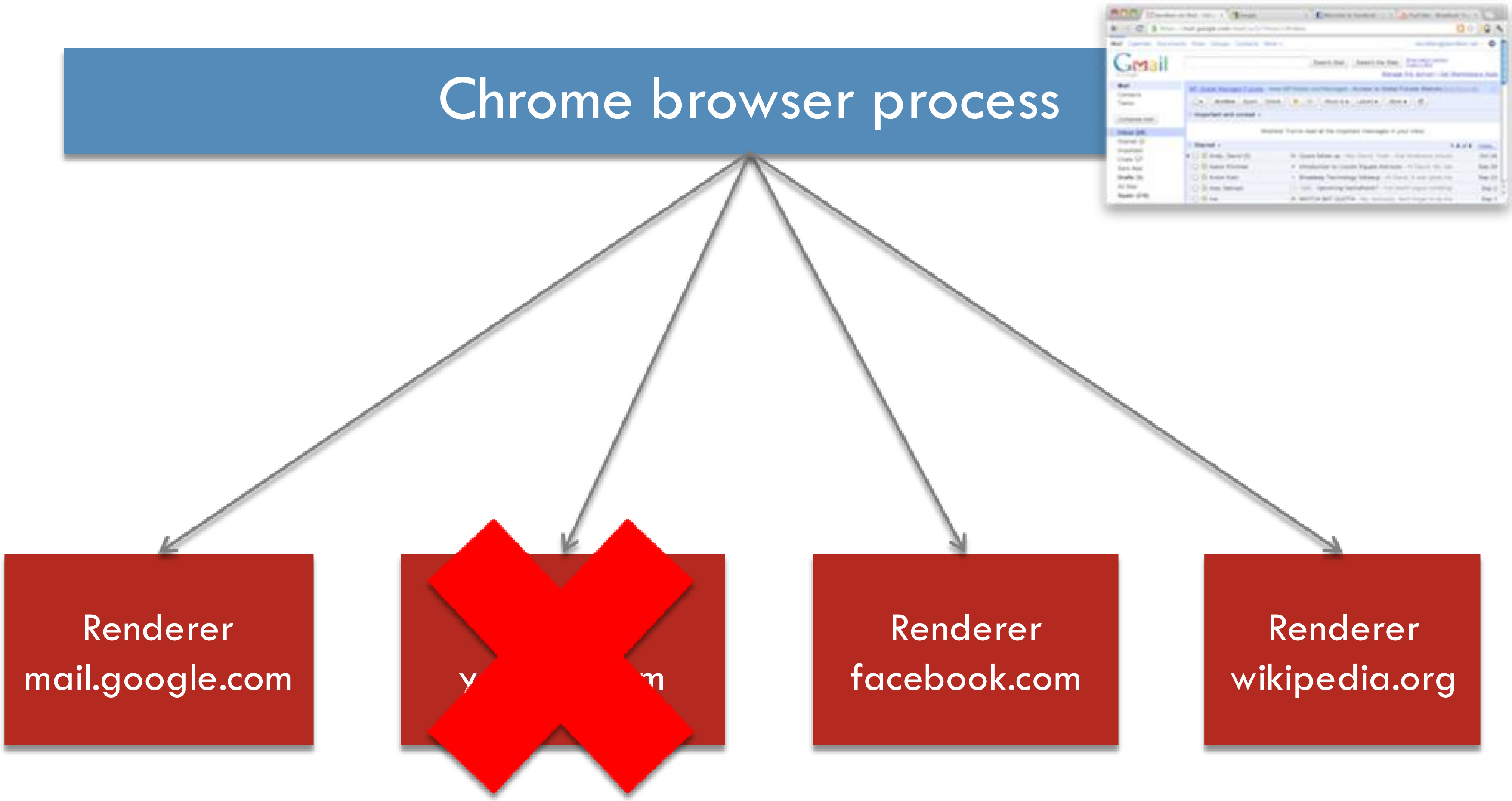
Chrome browser process



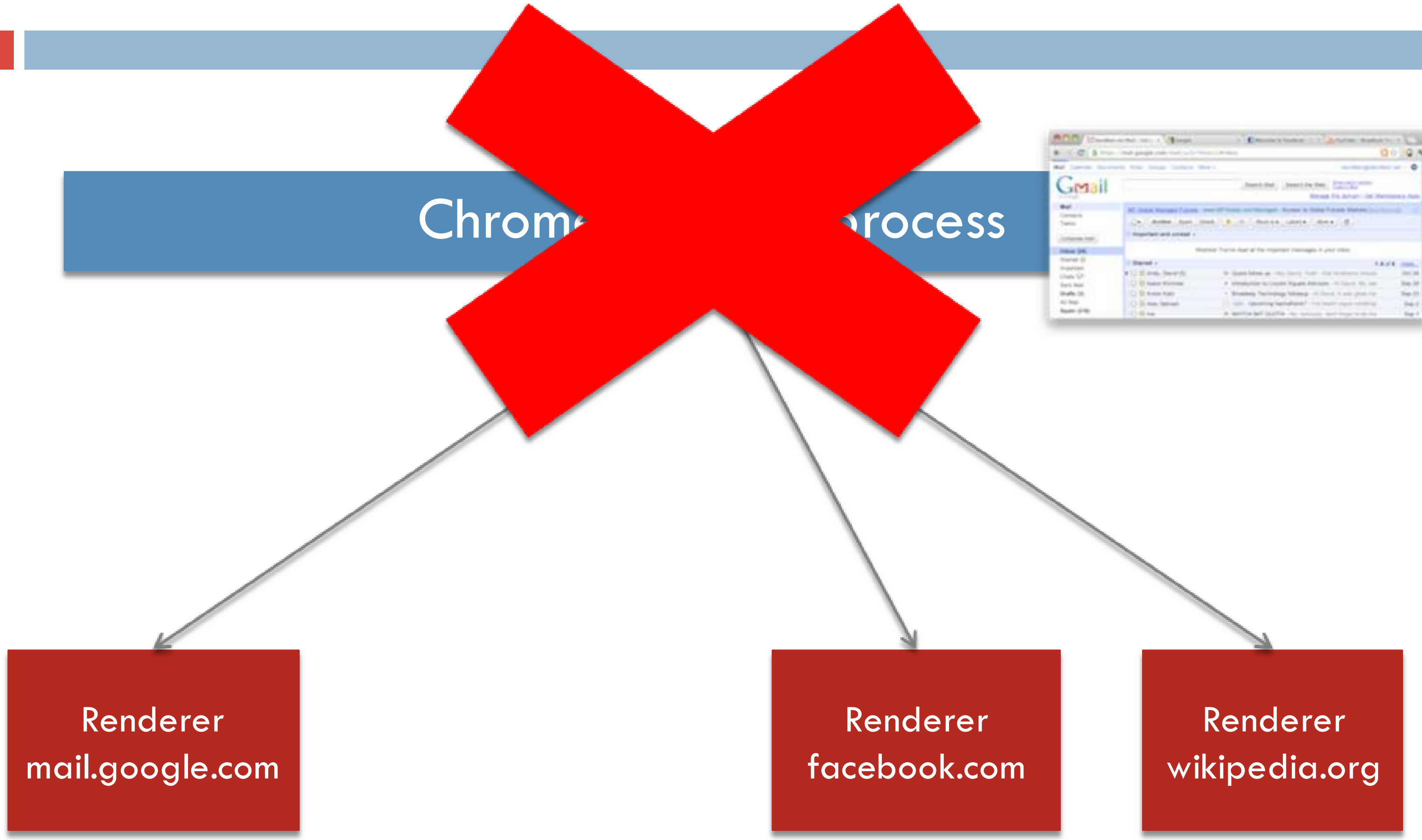
Multi-process browsing



Multi-process browsing



Multi-process browsing



Multi-process browsing

- Each tab in a separate renderer process
- Renderers coordinated by browser process
- Communicate by sending messages
- Renderer bugs are recoverable
  - Browser process crashes are still fatal

Playing in the sandbox

- How tab isolation works
- Sandboxing
- Principle of least privilege

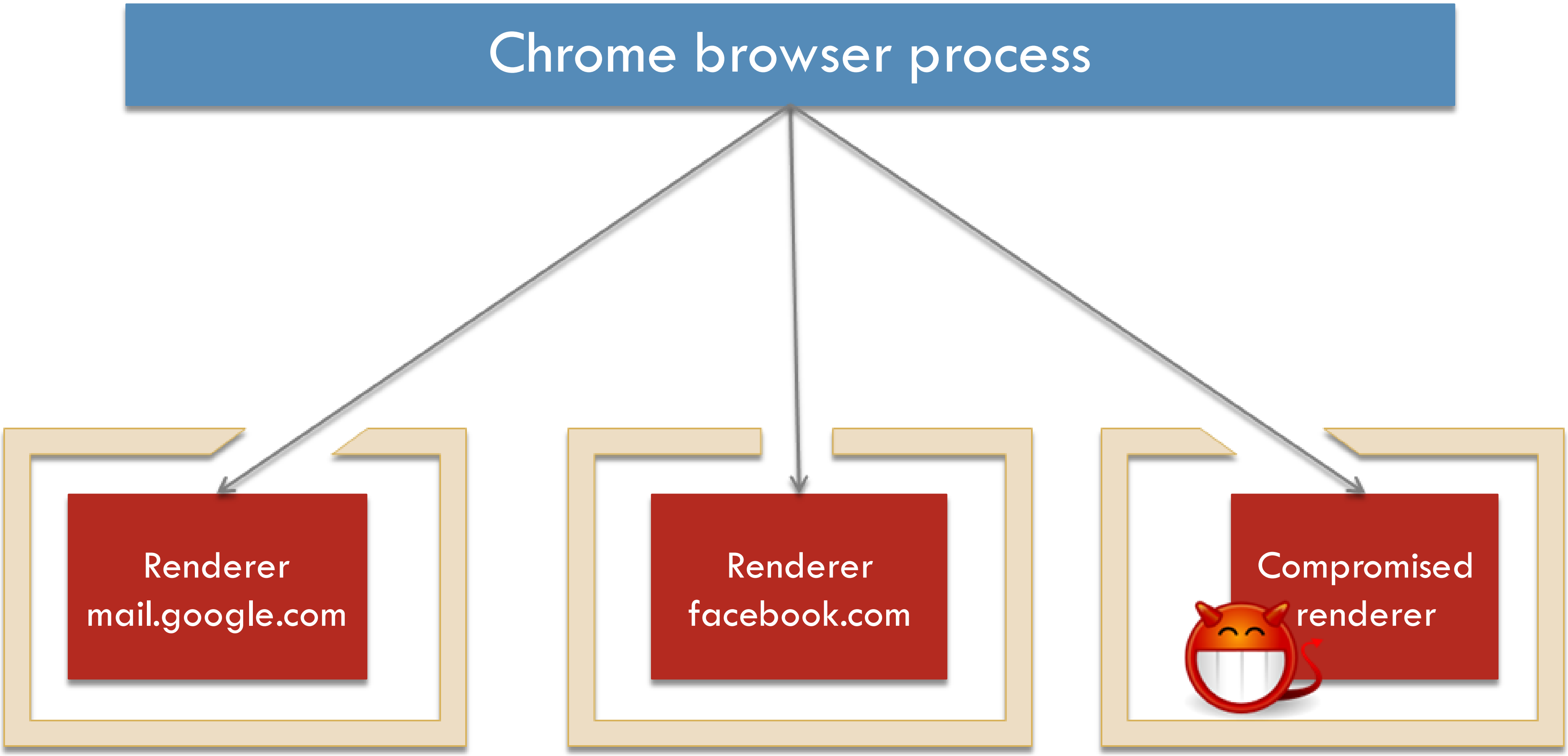
Browser security

- Webpages are very restricted
  - Cannot read your English paper
  - Cannot write a virus
  - Cannot delete your files
- Visiting evil.example.com should be safe
- Browser enforces these restrictions
- What if there is a bug?

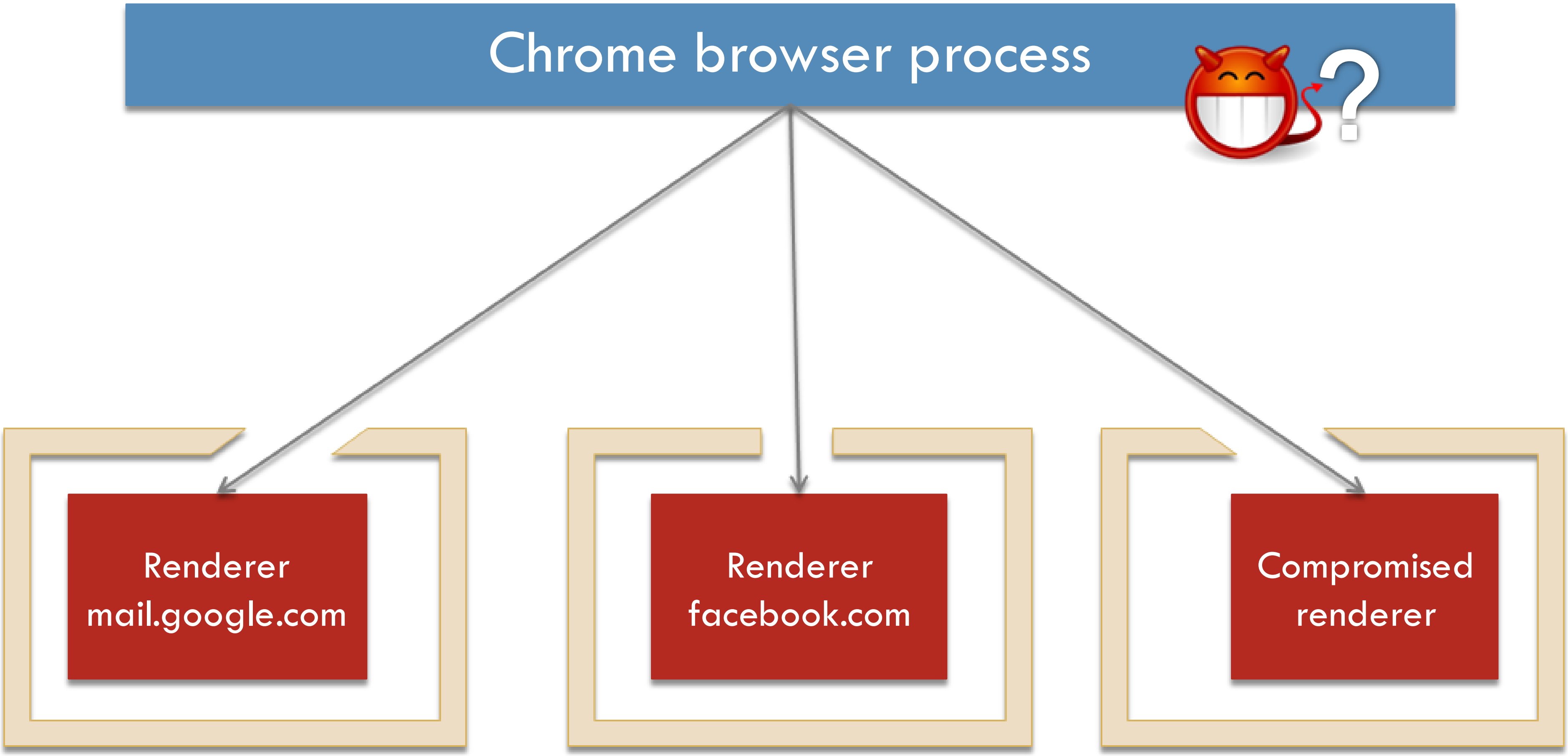
Enforcing security

- Sandbox each renderer
  - Can’t access files
  - Internet
  - Other processes
- Only communicate with browser
  - Performs privileged actions on behalf of renderer
  - Including network access

Enforcing security



Enforcing security



Playing in the sandbox

- How tab isolation works
- Sandboxing
- Principle of least privilege

Principle of least privilege

Each component of your system should have only the rights it needs and no more

- Limit damage when things go wrong
- Fewest privileges to parts most likely to fail

Playing in the sandbox

- All complex software is buggy, so design for bugs
- Separate renderer process per tab
  - Improved stability
  - Security
- Restrict renderer rights to bare minimum
- Principle of least privilege
- Questions?

What do we mean by "innovation"? *Purpose driven creativity*

An abstract sculpture?

Creative.

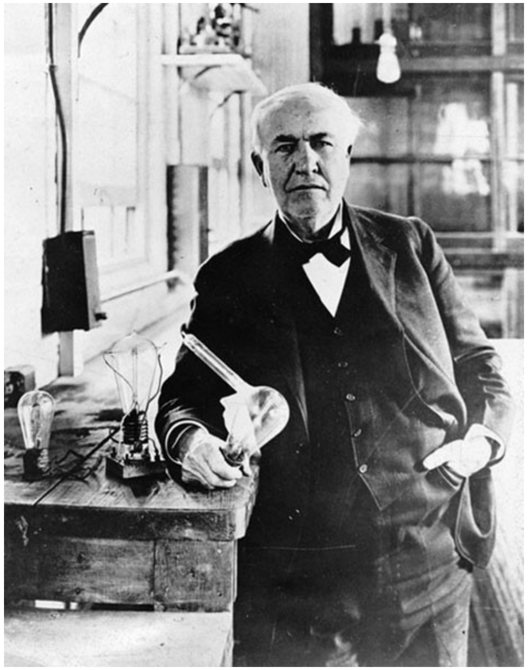
An abstract sculpture that prevents the wind from spinning a building's revolving doors too fast?

Innovative.

Distributed Innovation

There are a lot more smart people than geniuses

1 in a million?



Millions and billions.

New technologies enable collective genius

Culture and Persuasion

- Direct
- Hypothetical
- Individual
- High Agency
- Egalitarian

- Indirect
- Concrete
- Collective
- Fatalism
- Hierarchical

If wishes were horses…

No need to go all the way around Robin Hood's barn

Don't beat around the bush

The squeaky wheel gets the grease

Two heads are better than one

He who travels fastest travels alone

Many hands make light work

Too many cooks spoil the broth

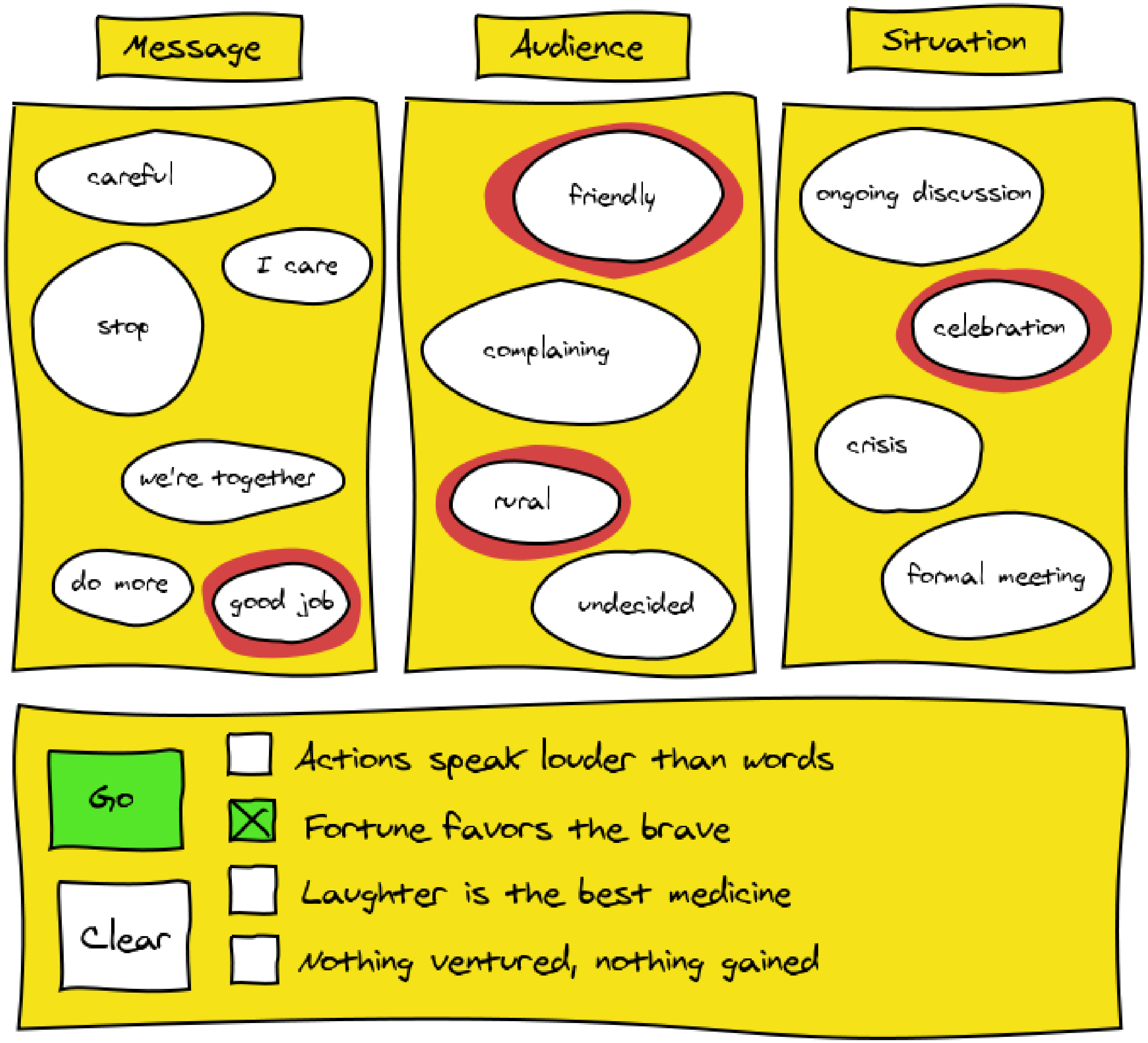
The nail that sticks up gets hammered down

If at first you don't succeed…

Better to light a single candle…

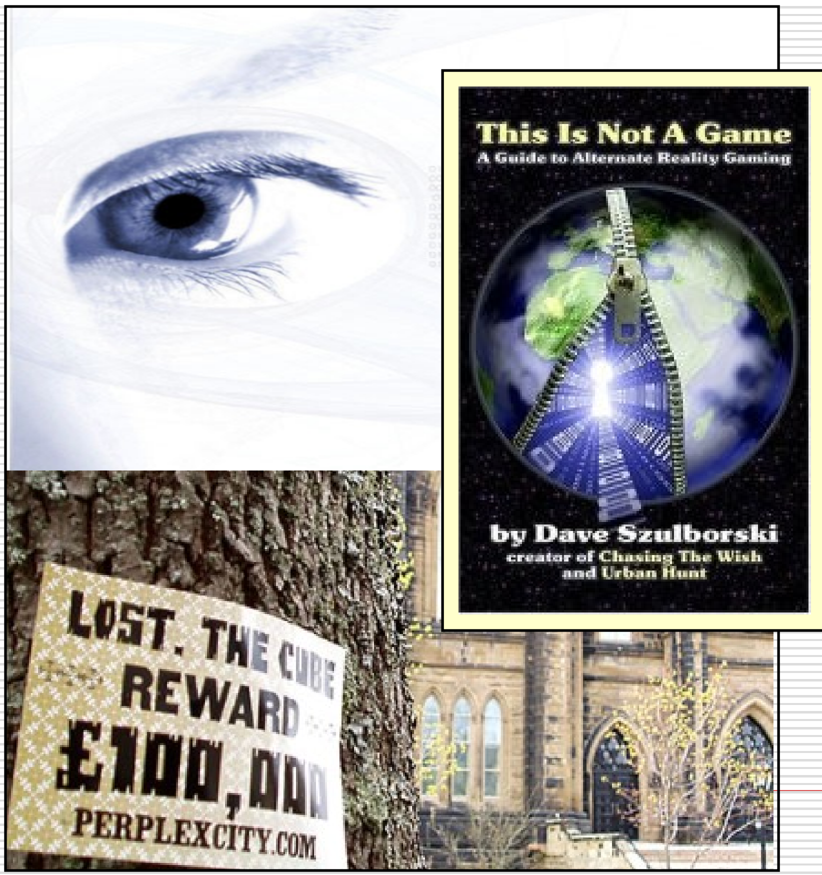
A cat can look at the king

Finding Possible Proverbs



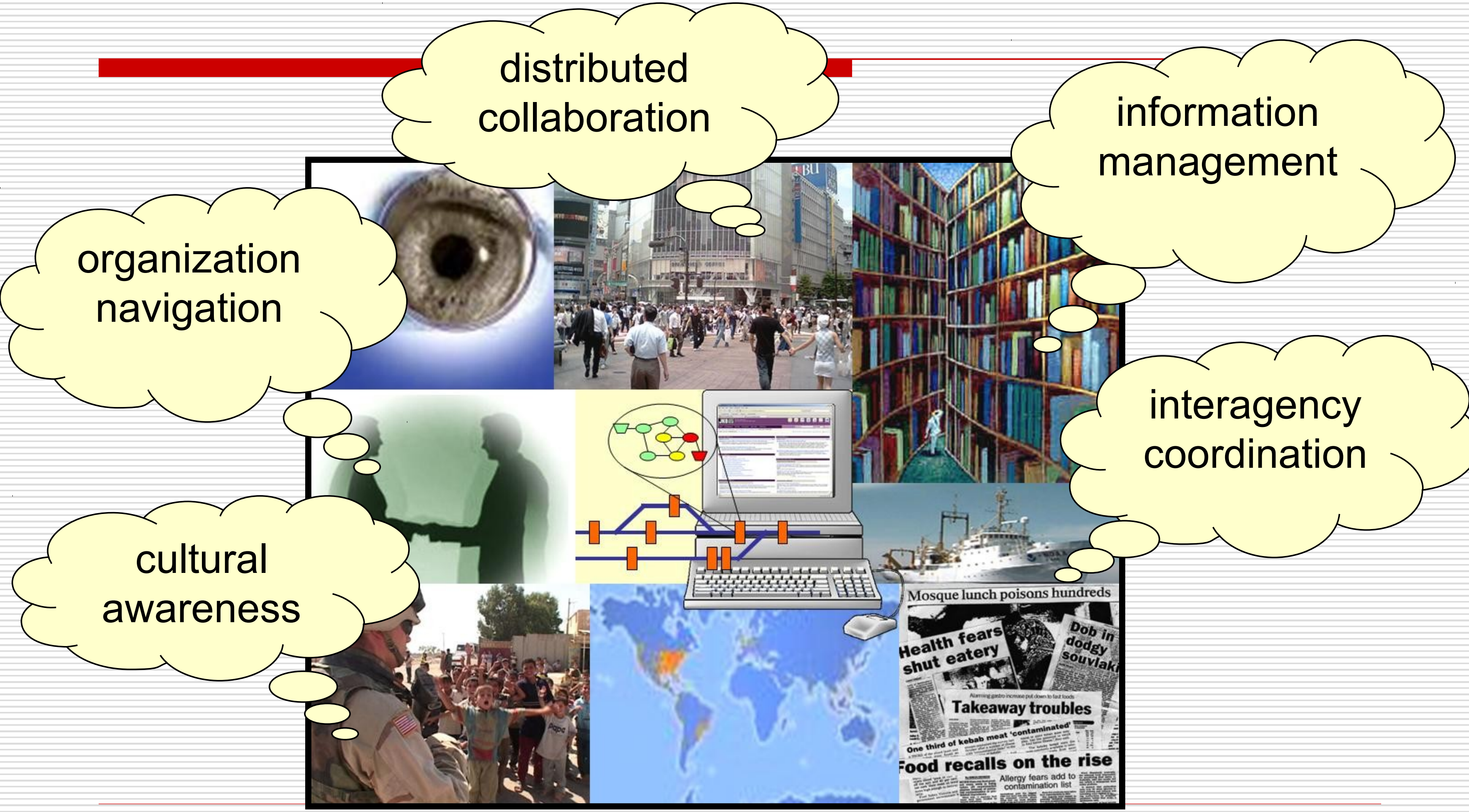
Inspirations For Helical Training

Alternate Reality Games



Large-scale exercises

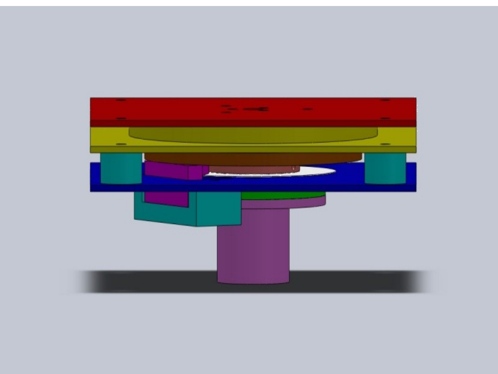
What Skills Could Be Learned?

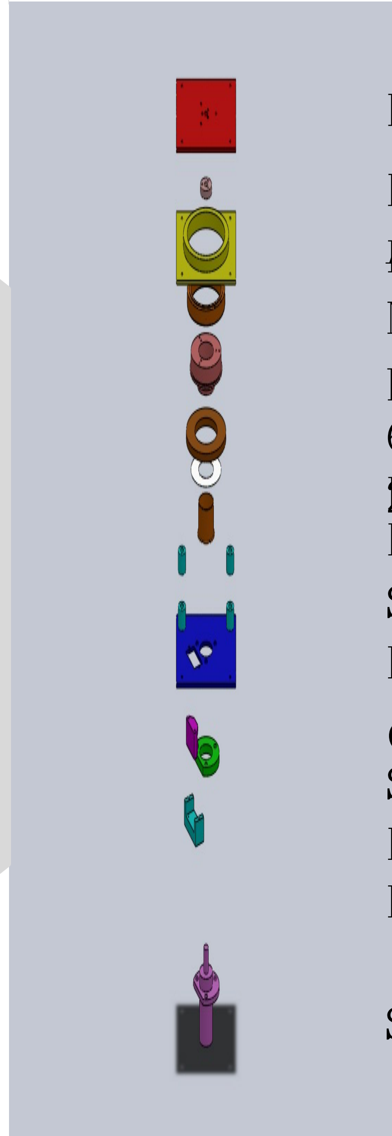


Sample Tasks

What would you learn if you walked through LA wearing 30 pounds of carrots, led a squirrel fishing party, challenged a dragon, asked for help inflating a large duck, and solicited strangers for a dinner invitation?

Spinner Assembly: Design Review





Payload Mounting Plate

Flexible Coupling Attachment

Bearing Housing

Multi-Load Bearing

Hollow Shaft

65 Tooth Steel Gear 65mm PD

2500 Tick Encoder Disk Insert

Spacers

Bus Cover Plate

Optical Encoder

Slip Ring Spacer

Encoder Mounting Bracket

Slip Ring

Not Shown:

- Micro DC Motor
- 15 Tooth Brass Gear 15mm PD
- Small Gear Mounting Collar
- Flexible Coupling

Spinner Assembly: Final Model

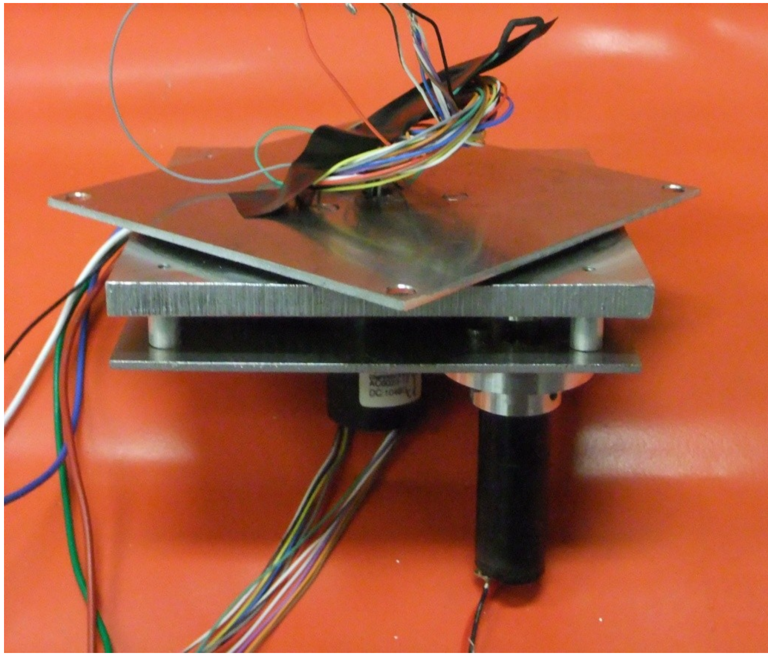
Specifications

Max Angular Velocity: 1.7 Hz

Motor Controller: Pololu QiK TTL Interface

Slip Ring Channels: 12

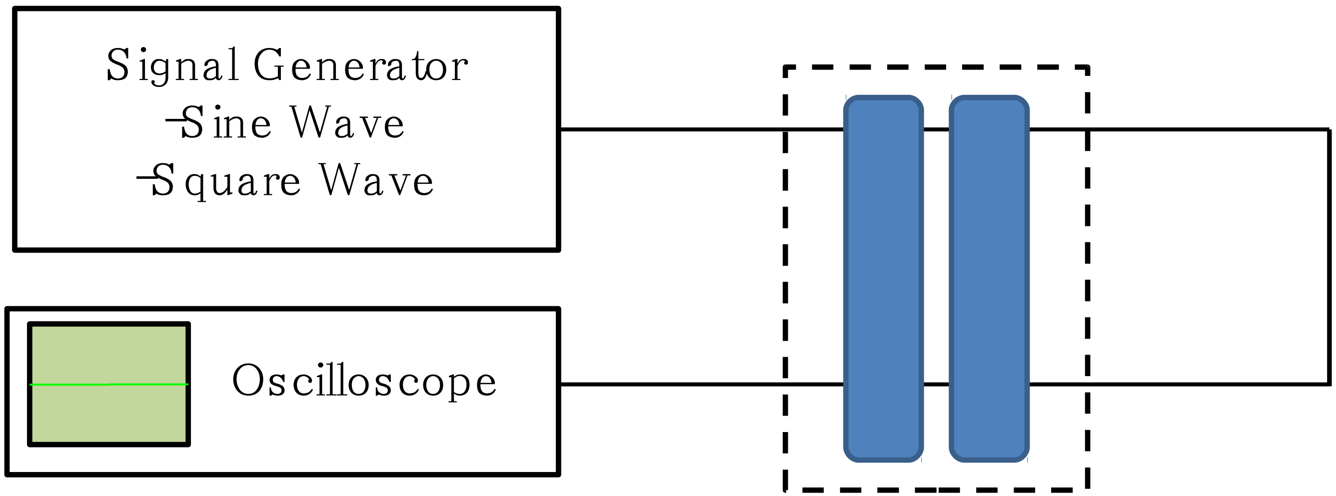
Dimensions (Interface Space): 100mm x 100mm x 18mm



Spinner Assembly:

Spinner Assembly: Qualitative Testing

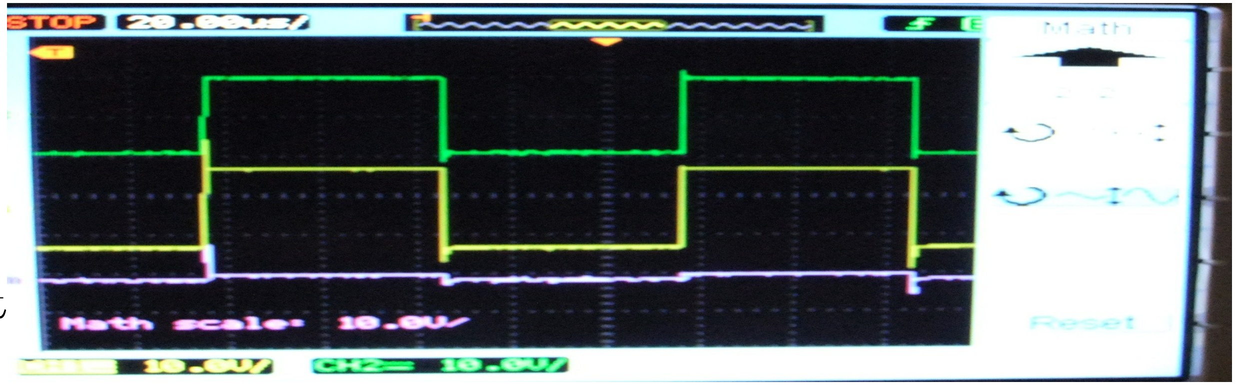
Setup:



Spinner Assembly rotating at 1.7Hz

Sample Square Wave Output (10 Volts/div, 1kHz):

Transmitted Signal



Input Difference

Spinner Assembly: Qualitative Testing

Results:

Noticeable signal distortion appears at frequencies >1 KHz

Significant signal distortion appears at signal frequencies >1 MHz

Conclusion:

I.I. seria

Problem

minima

5 MHz Sine Wave

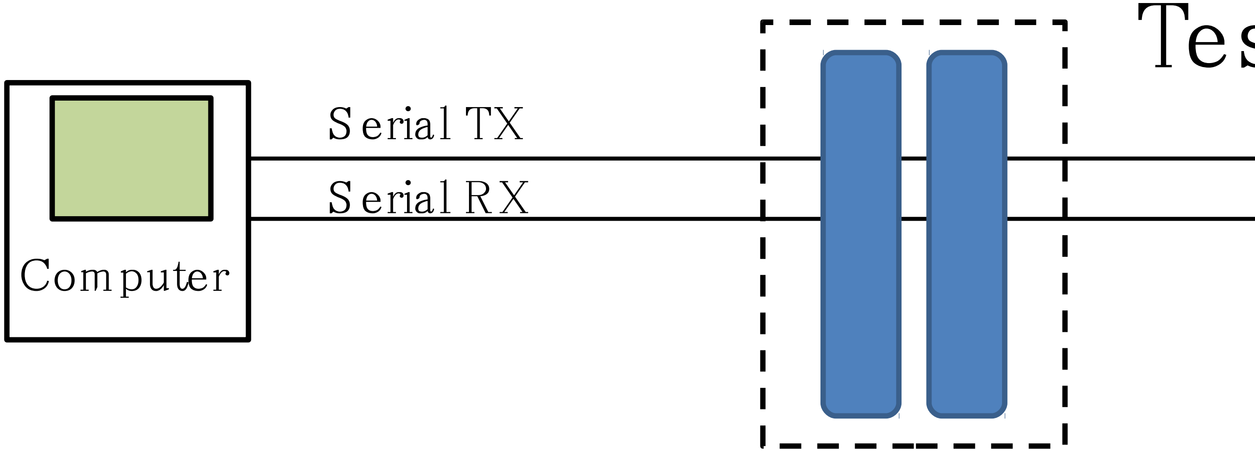
Transmitted Signal

Input

Difference

Spinner Assembly: Quantitative Testing

Setup:



Spinner Assembly rotating at 1.7 Hz

Results:

1,000,000 bytes sent; 0 errors

Error probability <0.0000054 with 99% confidence

Conclusion:

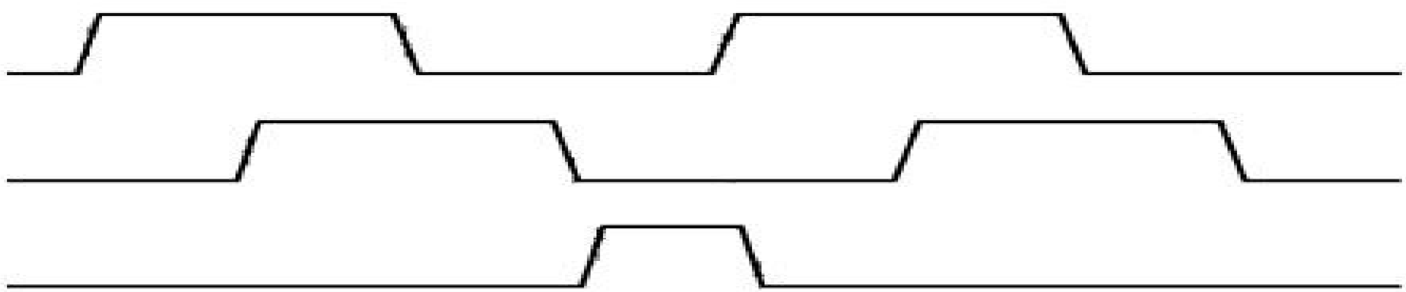
Slip ring interface is suitable for serial data

Massachusetts Institute of Technology

Spinner Assembly: Encoder Testing

Relative roll angle between the bus and payload is given by an optical encoder with 2 arc minute accuracy

US Digital Sample Timing Characteristics

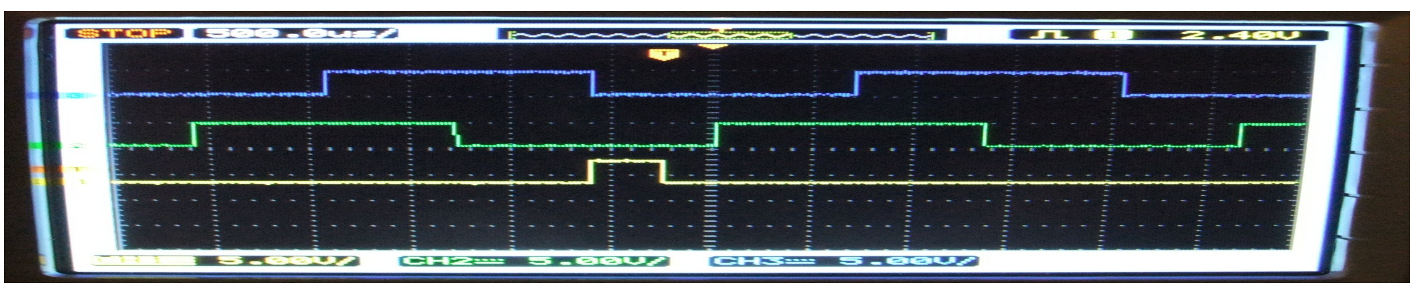


Channel A

Channel B

Index

Observed Timing Characteristics



Channel B

Channel A

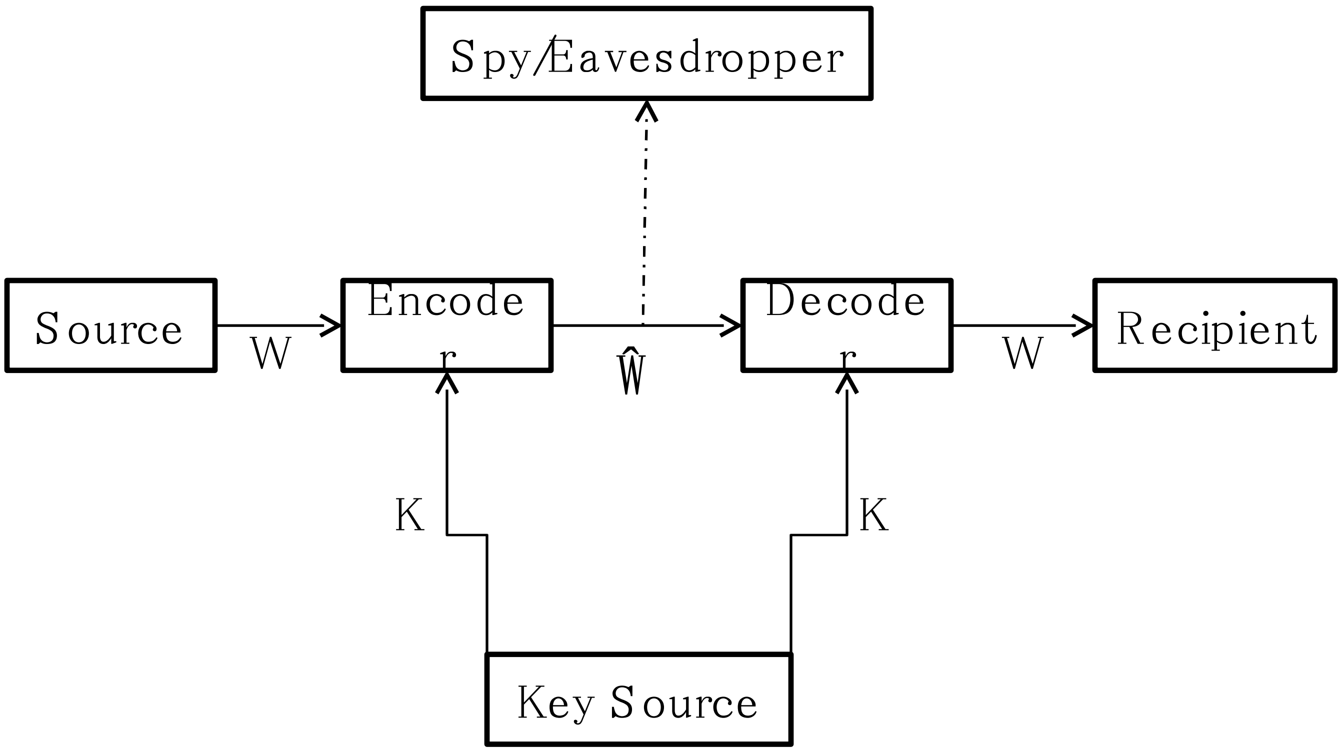
Index

Spinner Assembly: Summary

Spinner Assembly redesign was successful

Meets volume, data transmission and pointing knowledge requirements

Next Step: Selection of Space Rated Components


Spy/Eavesdropper
Source
W
Encoder
Ŵ
Decoder
W
Recipient
K
K
Key Source

The Photoelectric Effect

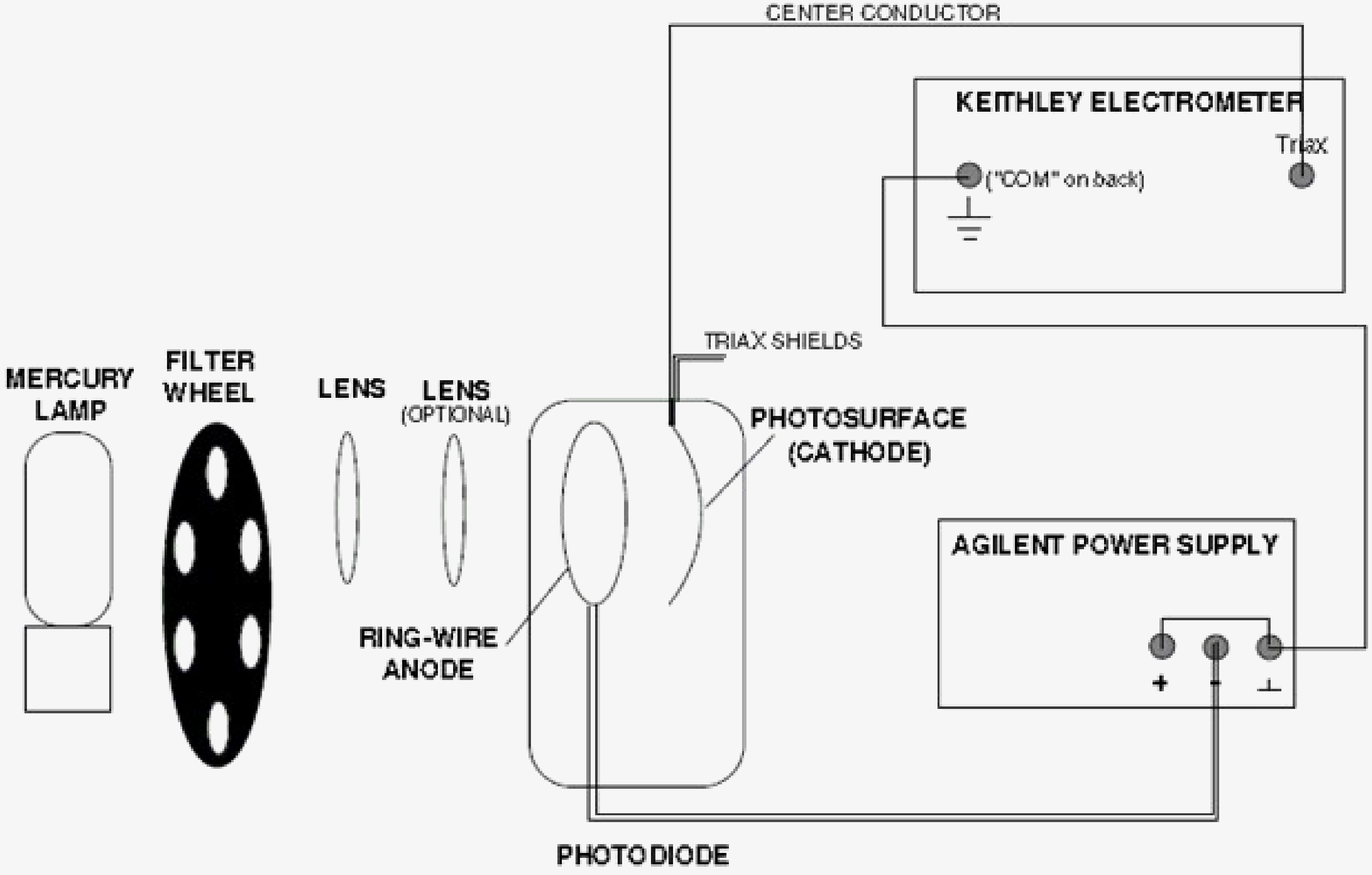
Matthew Houston
10/1/2010

Explanations–Classical and Quantum

- In 1887 Hertz observes a new phenomena
- No classical explanation exists
- In 1905 Albert Einstein proposes a quantum explanation

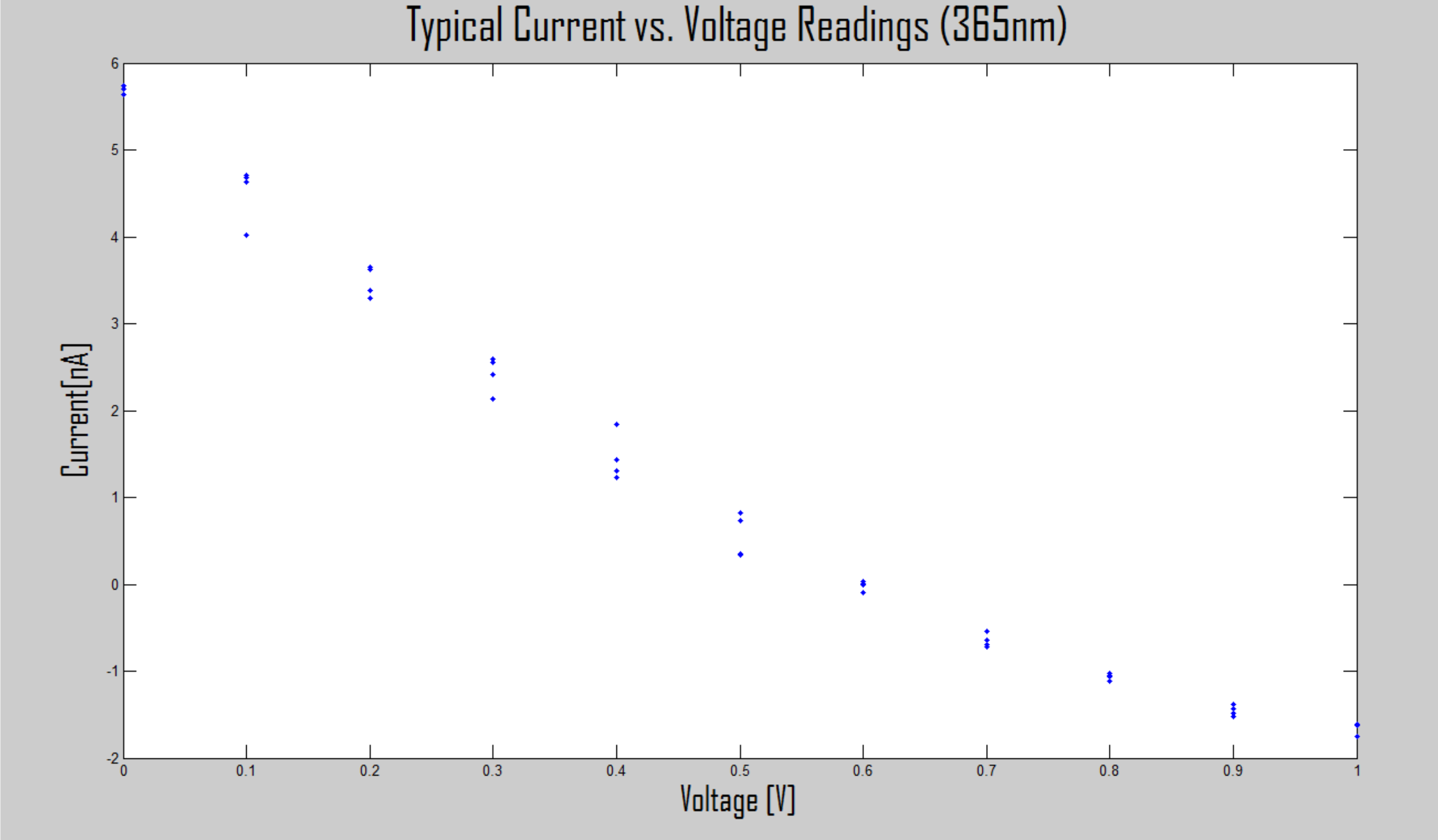
$$E_{photon} = h\nu \qquad KE_{max} = h\nu - \Phi$$

Experimental Setup



Raw Data–Voltage vs. Current

275 Current, Voltage pairs collected over 5 different wavelengths

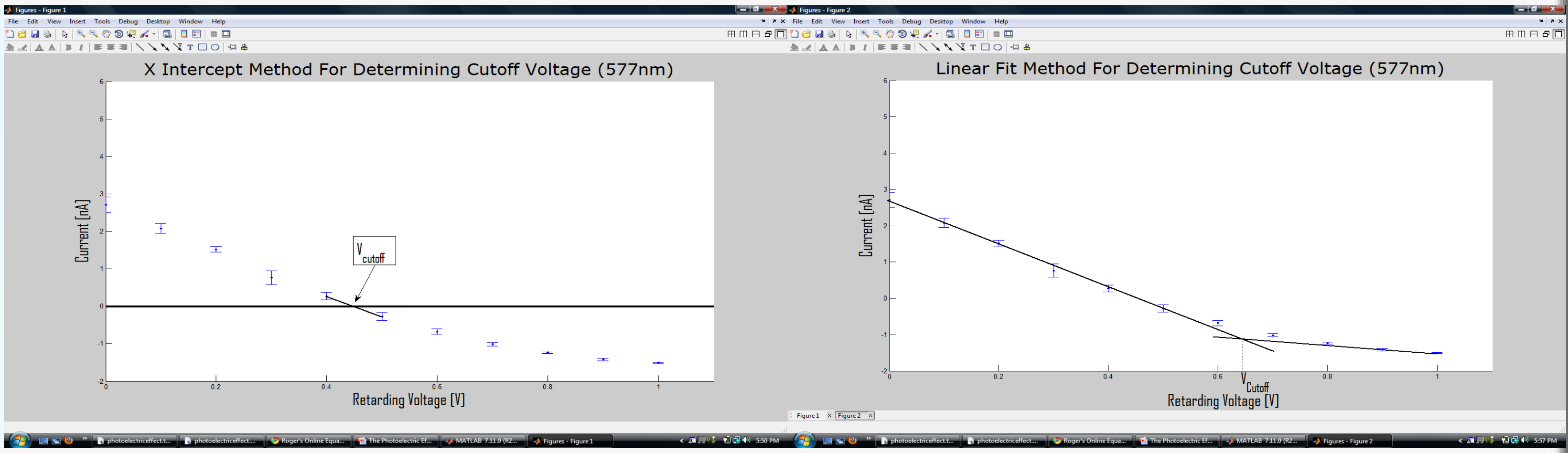


Finding the Cutoff Voltage

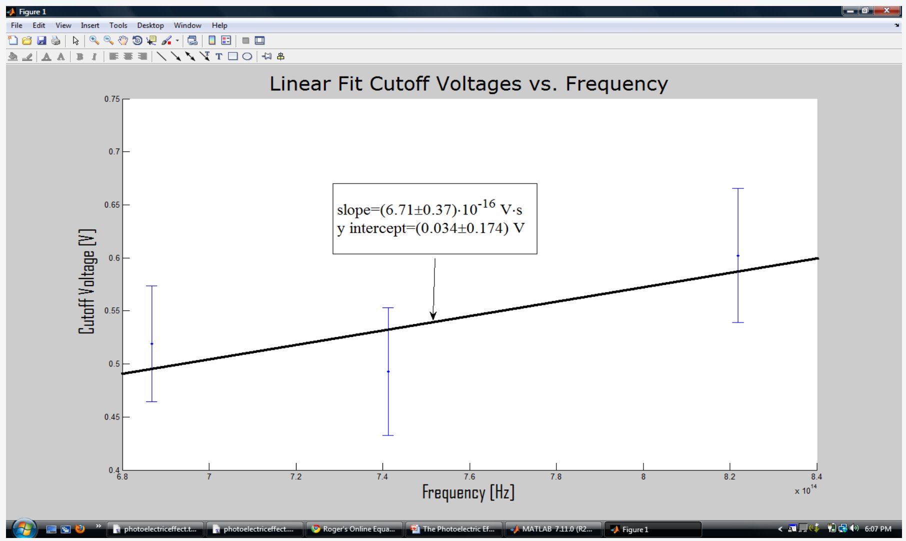
$$KE_{max} = h\nu - \Phi - eV_{retarding}$$

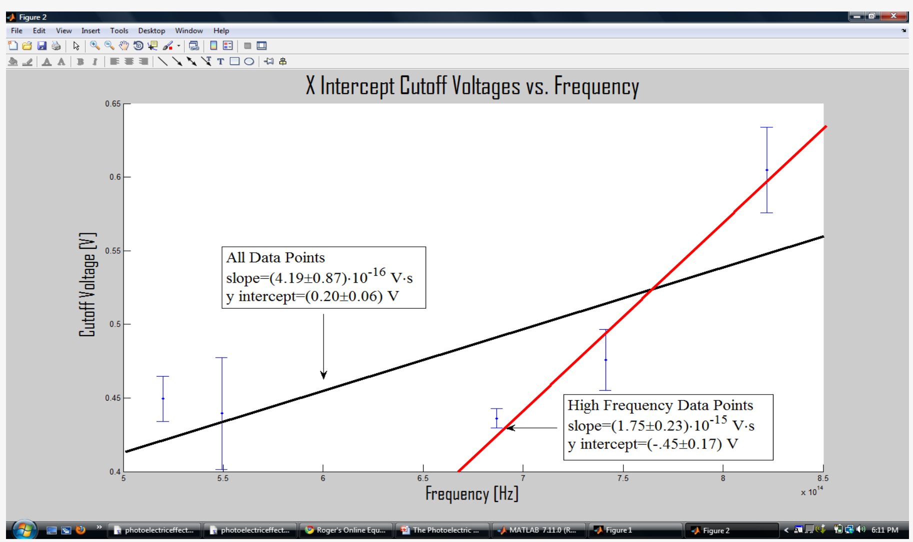
$$V_{cutoff} = \frac{h}{e}\nu - \frac{\Phi}{e}$$

Two Methods to determine $V_{cutoff} = \frac{h}{e}\nu - \frac{\Phi}{e}$



Graphical Results





Numerical Results

Method	Plank's Constant (Js)	Work Function (eV)
Linear Fit High Freq.	$(1.07 \pm 0.37) \cdot 10^{-34}$	0.03 ± 0.175
X-Intercept High Freq.	$(2.04 \pm 0.37) \cdot 10^{-34}$	-0.45 ± 0.175
X-Intercept All Data	$(6.72 \pm 1.40) \cdot 10^{-35}$	0.20 ± 0.06
Actual	$6.63 \cdot 10^{-34}$	2.3

Experimental results differ from known values by at least an order of magnitude (several standard deviations)

Systematic Error

Potassium build up on the anode causes reverse photoelectric currents

Insufficient Higher Voltage Data

Questions
?

The SPHERES IDE

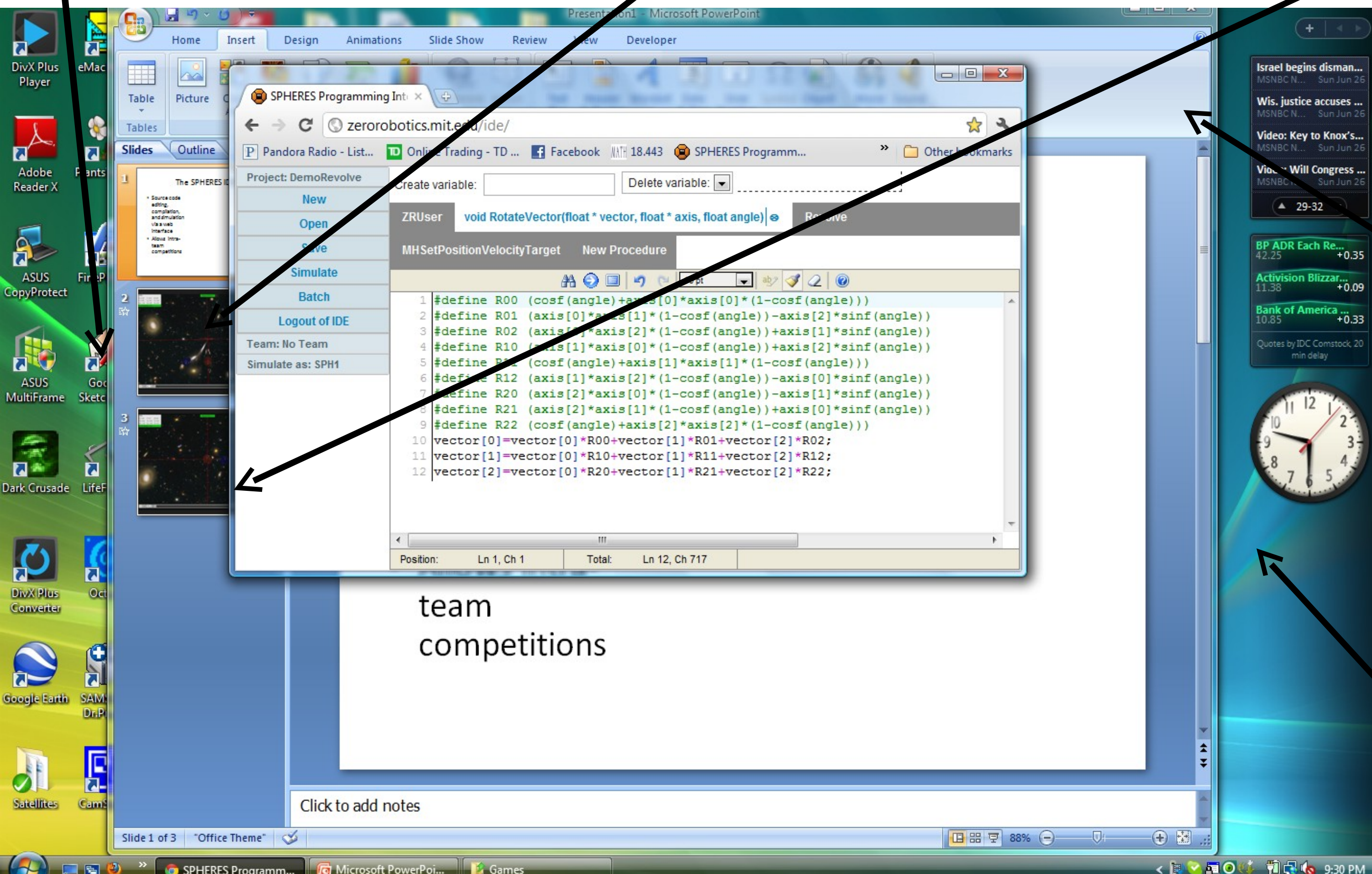
Simulate flight aboard the ISS

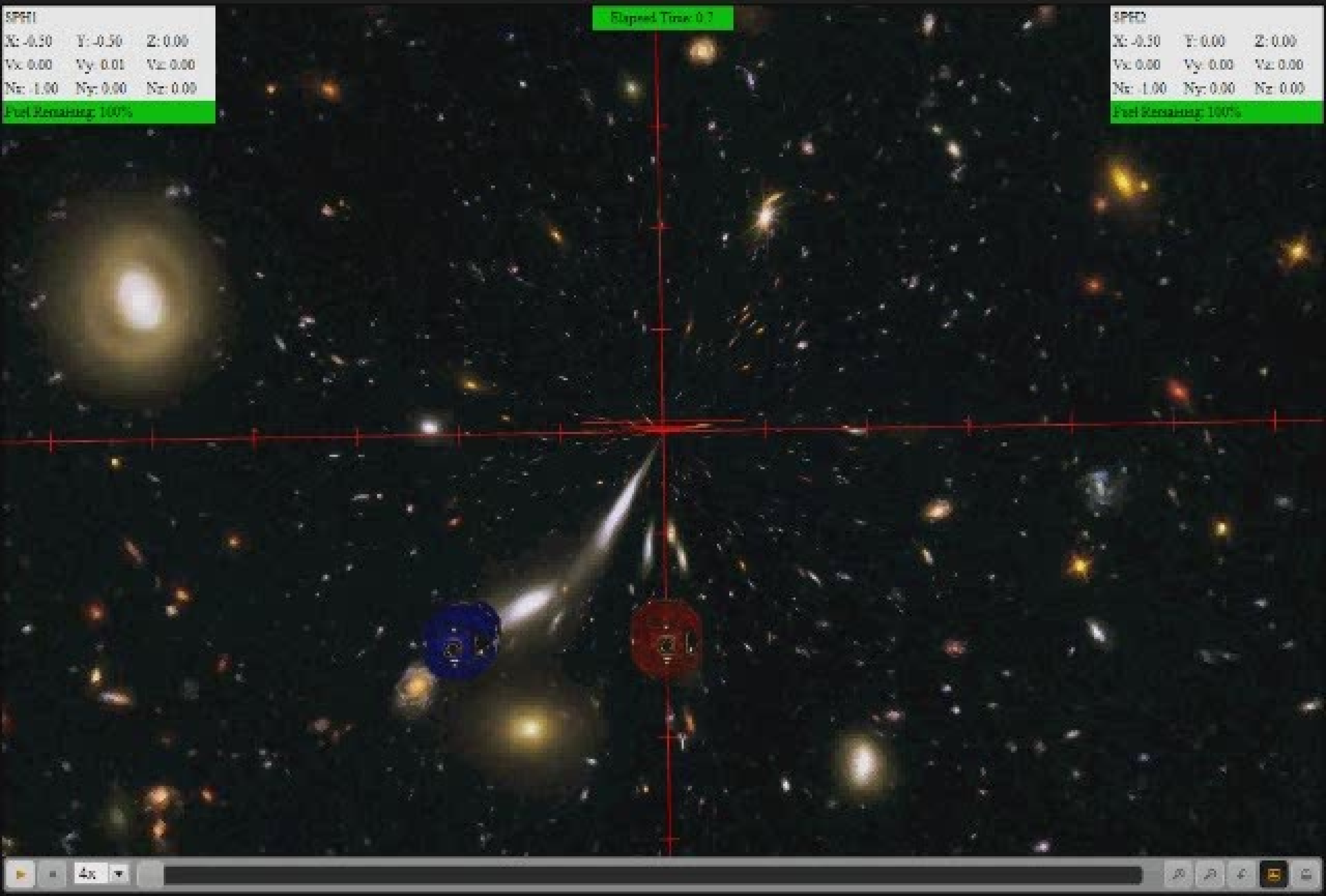
Automatic Version Control

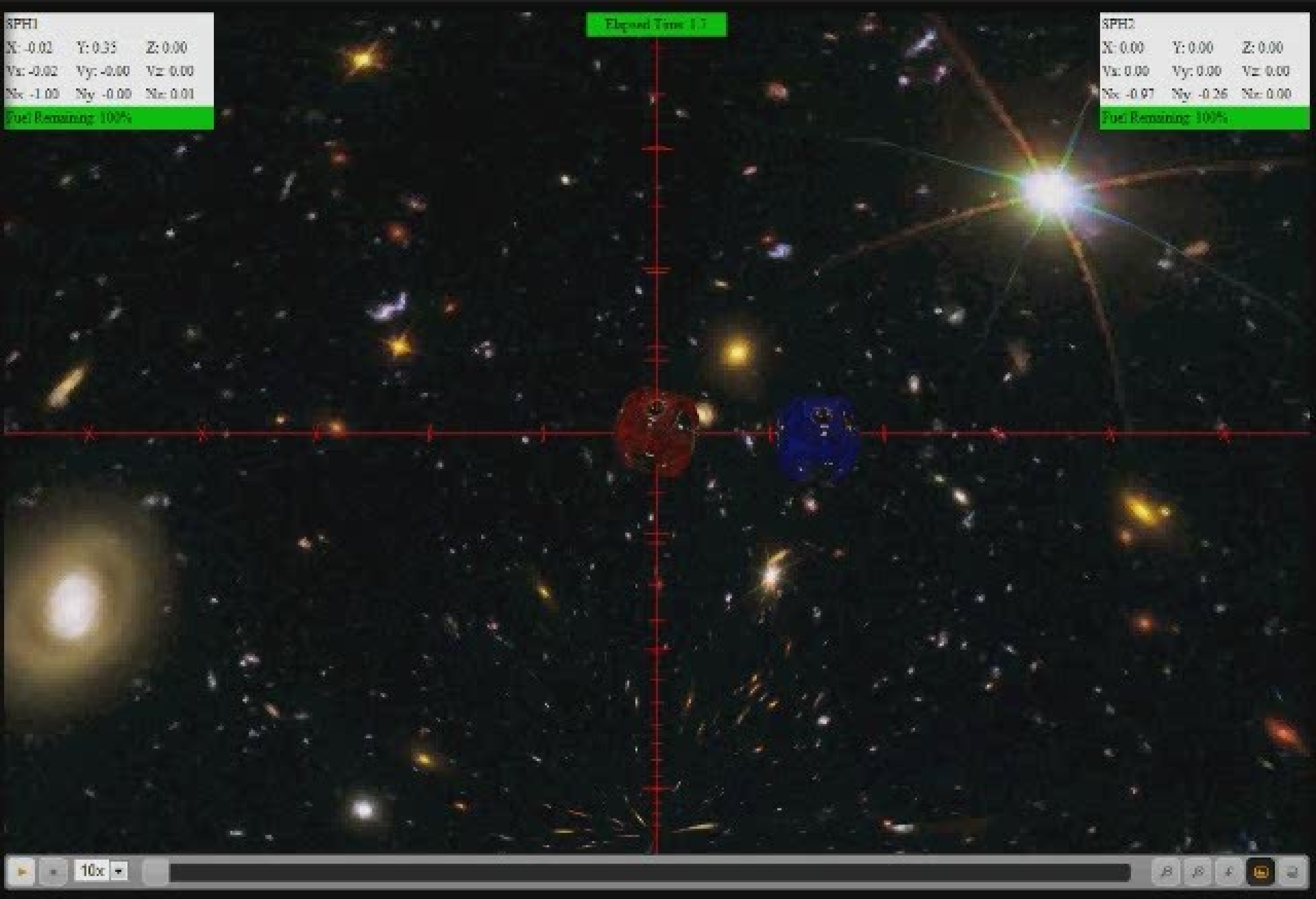
Compete with other teams

Web-based

Write and compile C-code




SPH1
X: -0.50 Y: -0.50 Z: 0.00
Vx: 0.00 Vy: 0.01 Vz: 0.00
Nx: -1.00 Ny: 0.00 Nz: 0.00
Fuel Remaining: 100%
Elapsed Time: 0.7
SPH2
X: -0.50 Y: 0.00 Z: 0.00
Vx: 0.00 Vy: 0.00 Vz: 0.00
Nx: -1.00 Ny: 0.00 Nz: 0.00
Fuel Remaining: 100%
4x


SPH1
X: -0.02 Y: 0.35 Z: 0.00
Vx: -0.02 Vy: -0.00 Vz: 0.00
Nx: -1.00 Ny: -0.00 Nz: 0.01
Fuel Remaining: 100%
Elapsed Time
SPH2
X: 0.00 Y: 0.00 Z: 0.00
Vx: 0.00 Vy: 0.00 Vz: 0.00
Nx: -0.97 Ny: -0.26 Nz: 0.00
Fuel Remaining: 100%
10x

The SPHERES Process