ECE 510 Quality and Reliability Engineering
Lecture 1. Introduction, Monte Carlo

Scott Johnson
Glenn Shirley

Today

- Introduction to the ECE 510 course
- Introduction to quality and reliability concepts
- A sample exercise showing the sort of exercise we will do most days in this class

Course Introduction

Instructor Biographies

- C. Glenn Shirley
  - PhD in Physics (ASU). 7 years at Motorola, 23 at Intel mostly in TD Q&R. Retired in 2007. Joined PSU ECE in the IC Design and Test Lab in 2008 as an Adjunct Prof.
- Scott C. Johnson
  - PhD in Physics (U of CA Davis). 11 years at Intel as a reliability engineer and statistician. Before that, BS in Electrical Engineering (U of IL) and 5 years at Lockheed.
- Course will be co-taught by Glenn and Scott.

Course Goals

- Provide knowledge and skills required of a QRE for integrated circuit
  - Product design
  - Product development
  - Technology development
  - Manufacturing
- Understand the essential trade-offs among
  - Cost
  - Performance
  - Quality and Reliability
  - Producer and Customer risks
- Learn how to assess risks and write qualification plans.
- Develop skills to use statistical methods and tools such as SQL and Excel to analyze data, develop models and make decisions.

Skills

- Calculate failure rates, MTTF, etc. including confidence limits.
- Design a reliability experiment and fit data to a model.
- Use the reliability model to calculate figures of merit for various design “what-ifs” and hypothetical manufacturing and use specifications.
- Use Monte-Carlo simulation to model complicated real-world scenarios which are intractable by classical statistical methods.
- Design a reliability validation plan.
- Be able to build system-level quality and reliability models from component-level models.
- Design a statistical manufacturing monitor or control chart with specified producer and customer risk levels.
- Handle large datasets using SQL and Excel, and so..
- Compute test statistics such coverage, yield, test time, customer defect level from test data.

Logistics

- 4 credits, Monday and Wednesday, 5:00pm–6:50pm, 10 weeks
- Format is lecture and in-class exercises intermingled.
- Lecture will be recorded and accessible online. But in-class activities will not be recorded.
- Presentation materials will be posted to internet right after the class in which they are presented.
- In-class exercises usually will require a computer running Microsoft Excel.
  - Other spreadsheet programs (e.g., Open Office, Google Docs) might work.
  - Later in the course we may use SQLite Expert.
- Recommended textbook is Tobias & Trindade, Applied Reliability, 3rd ed.
- Watch the web site for
  - Schedule changes.
  - Reading assignments, including links to extra materials.
  - Presentation materials, and lecture recording.

Grading Model

- Homework. 25% of grade.
  - 16 exercises; one per class with exceptions for exam week, etc.
  - Due by 3P on day one week following assignment.
  - All homework will be submitted electronically.
  - Unless noted, homework is expected to be an individual effort. Discussion is OK, but copying is not.
  - Best 14 of 16 will be used to determine “Homework” part of grade.
- Exams. Mid-Term, 25% of grade. Final, 40% of grade.
  - Open-book, open to slides, open Excel, but offline - closed to internet.
  - Final exam will cover entire course (1/3 pre-midterm, 2/3 post-midterm).
  - Material covered in exams will be from lecturer’s presentation materials, not the text unless referred to in presentation materials.
- Attendance. 10% of grade.
  - Attendance for class exercises is important for understanding.
  - Up to 2 unexcused absences with no loss of credit for attendance (18/20).

Syllabus

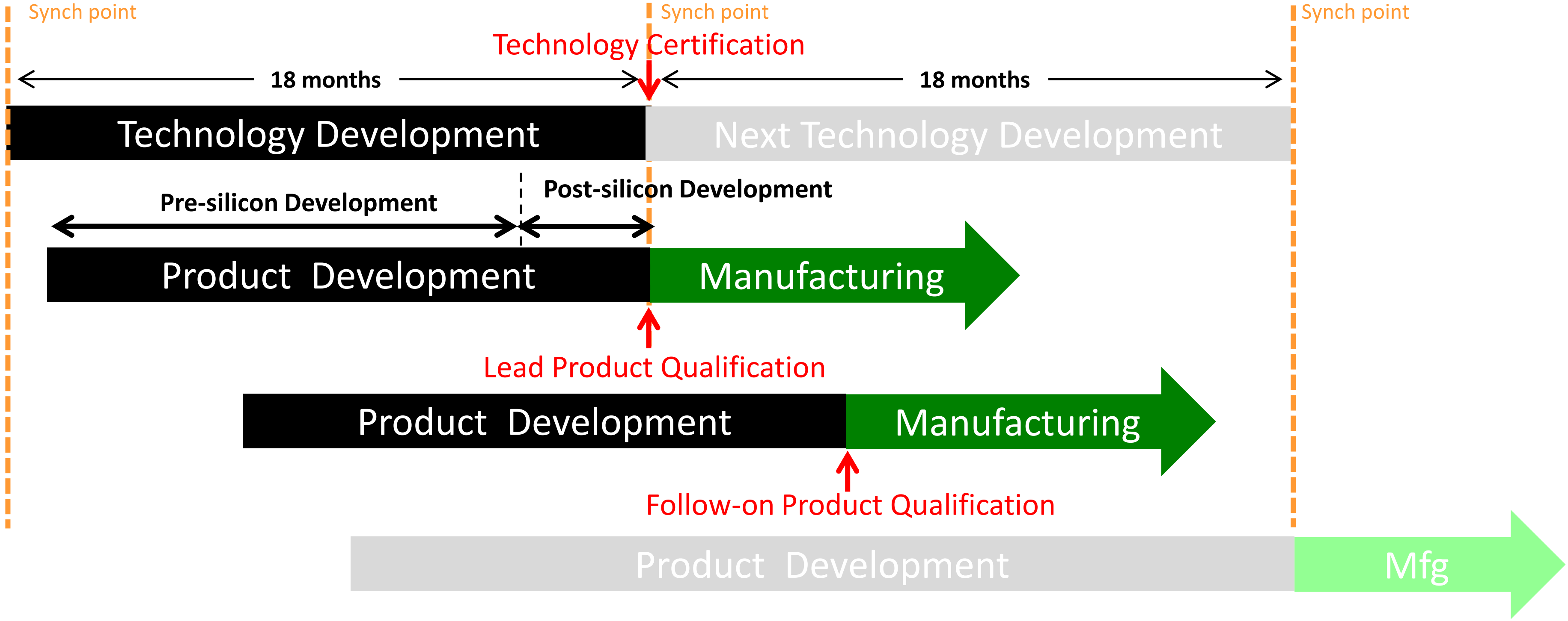
Date	Week	Day	Title	Owner
7-Jan	1	Mon	Introduction and Excel Exercise	Scott & Glenn
9-Jan		Wed	Plotting and Fitting Data 1	Scott
14-Jan	2	Mon	Introduction to Quality & Reliability	Scott & Glenn
16-Jan		Wed	Statistics 1	Scott
21-Jan	3	Mon	Statistics 2	Scott
23-Jan		Wed	Plotting and Fitting Data 2	Scott
28-Jan	4	Mon	Plotting and Fitting Data 3	Scott
30-Jan		Wed	Plotting and Fitting Data 4	Scott
4-Feb	5	Mon	Plotting and Fitting Data 5	Scott
6-Feb		Wed	Reliability Mechanisms 1	Scott
11-Feb	6	Mon	Reliability Mechanisms 2	Glenn
13-Feb		Wed	Midterm Exam	
18-Feb	7	Mon	Reliability Mechanisms 3	Bill Roesch, Triquint
20-Feb		Wed	Seminar (Follow-on from Bill and other Mechanisms lectures)	Bill, Scott, Glenn
25-Feb	8	Mon	Qual Methodology	Glenn
27-Feb		Wed	Qual Methodology	Glenn
4-Mar	9	Mon	Test Methodology I (Description of Test)	Glenn
6-Mar		Wed	Test Methodology II	Glenn
11-Mar	10	Mon	Test Methodology III	Glenn
13-Mar		Wed	Review Session	Glenn & Scott
18-Mar	Exam Week	Mon	Final Exam Mon or Wed.	
20-Mar		Wed		

Introduction to
Quality and Reliability Engineering

Semiconductor Manufacturing

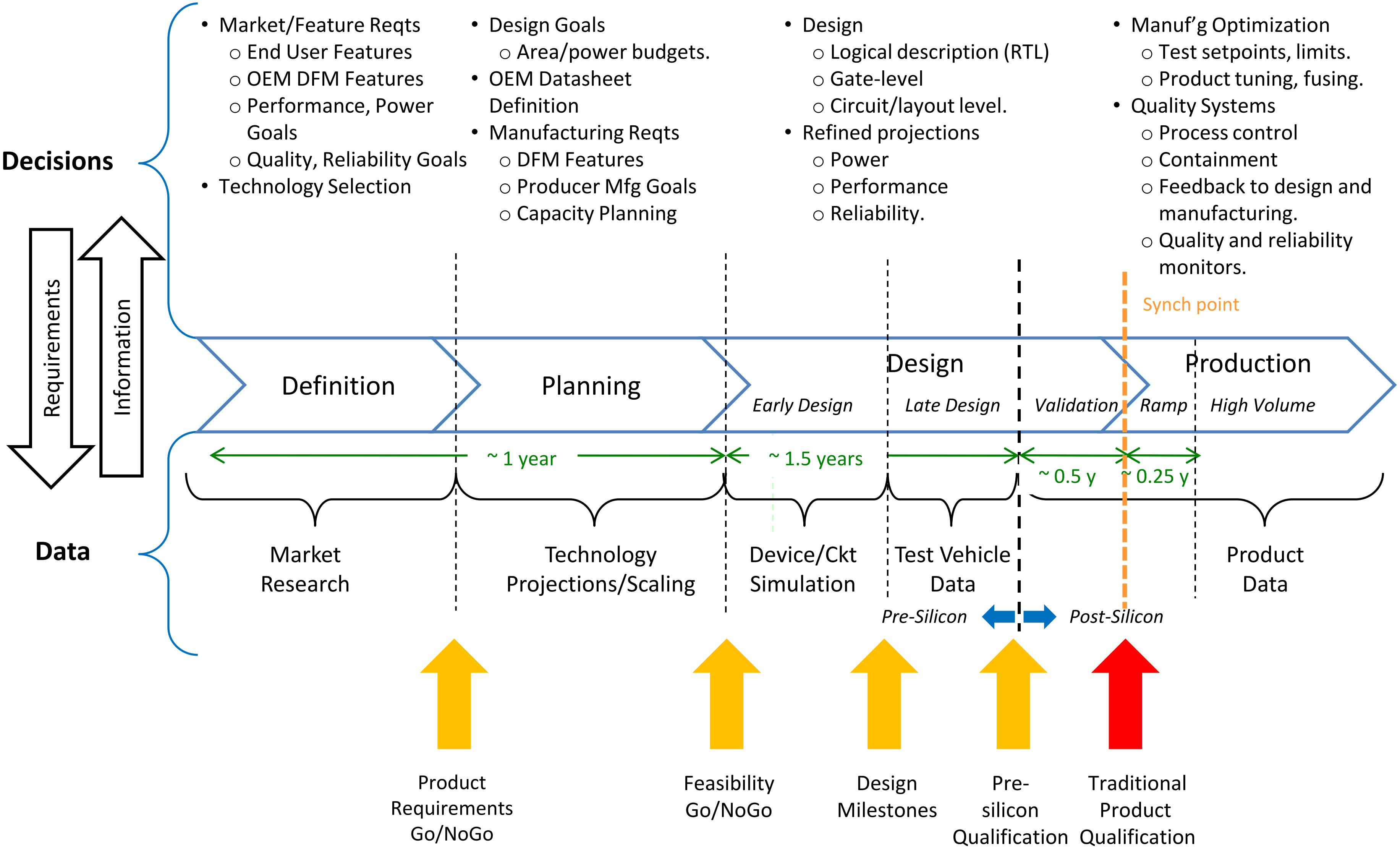
How Moore's Law Works

- Transistor density doubles every 18 months (Moore's Law).
- New products take 1.5 to 2 years from conception to manufacture.
- Technology development and product design must occur *in parallel*.



- QRE is involved at *all stages* of the Technology and Product Lifecycles.
- QRE role is control of customer quality and reliability risks.

Product Lifecycle



Decisions

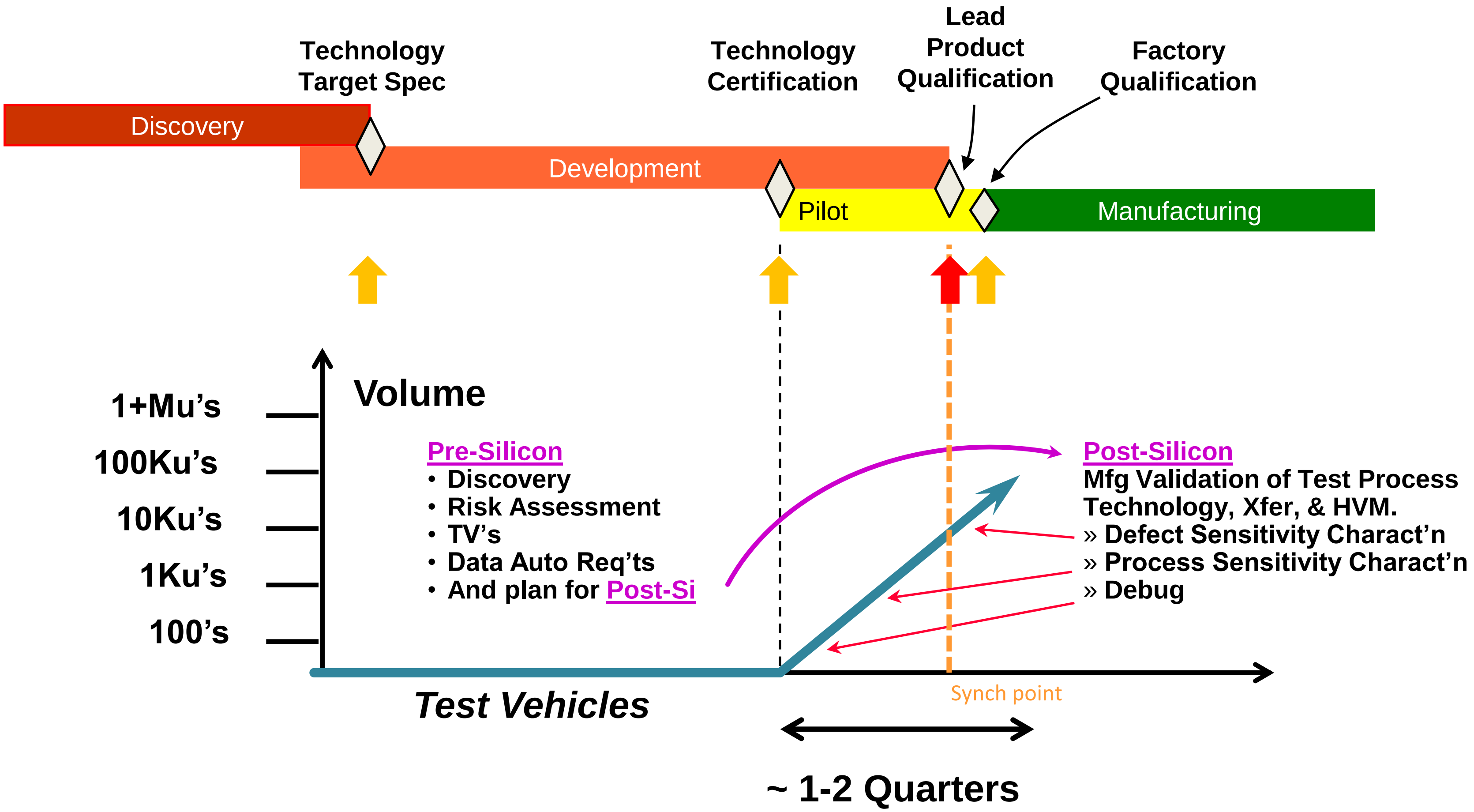
- Market/Feature Reqts
  - End User Features
  - OEM DFM Features
  - Performance, Power Goals
  - Quality, Reliability Goals
- Technology Selection

- Design Goals
  - Area/power budgets.
- OEM Datasheet Definition
- Manufacturing Reqts
  - DFM Features
  - Producer Mfg Goals
  - Capacity Planning

- Design
  - Logical description (RTL)
  - Gate-level
  - Circuit/layout level.
- Refined projections
  - Power
  - Performance
  - Reliability.

- Manuf'g Optimization
  - Test setpoints, limits.
  - Product tuning, fusing.
- Quality Systems
  - Process control
  - Containment
  - Feedback to design and manufacturing.
  - Quality and reliability monitors.

Technology Lifecycle



Pre-Silicon
- Discovery
- Risk Assessment
- TV's
- Data Auto Req'ts
- And plan for **Post-Si**

Post-Silicon

Mfg Validation of Test Process Technology, Xfer, & HVM.

» Defect Sensitivity Charact'n
» Process Sensitivity Charact'n
» Debug

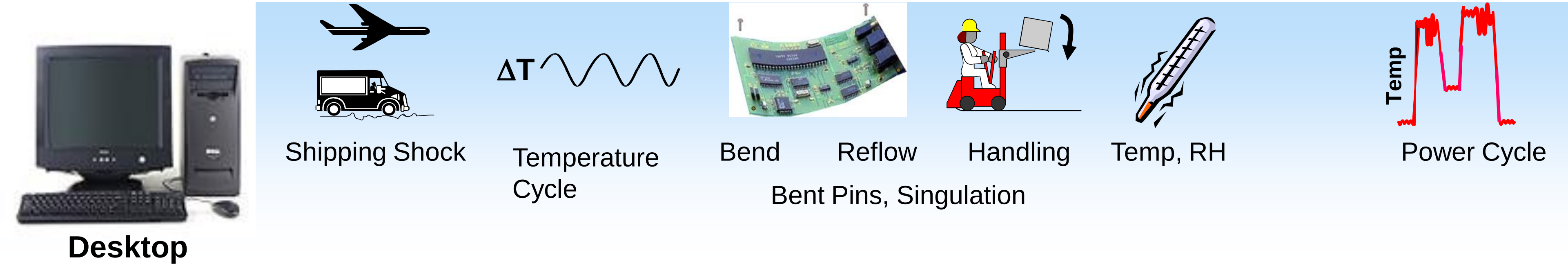
Quality

Role of the Q&R Engineer (QRE)

- The QRE is a proxy for the customer, at all stages of the Product and Technology lifecycles, and
  - *Gives Q&R Requirements.* Provide quality and reliability requirements for products, technologies, and manufacturing.
  - *Assesses Risk.* Assess product, technology, and manufacturing risks.
  - *Writes Validation Plans.* Technology Certification, Product Qualification.
  - *Designs Experiments.* Provides requirements to acquire needed data.
  - *Builds Q&R Models*. What-if models providing estimates of Q&R figures of merit to enable decision-making involving Q&R attributes of the product.
- Kinds of QRE
  - *Technology Development QRE.* Silicon and Package reliability models, burn-in development. Process Certification.
  - *Test QRE.* Fault coverage analysis and modeling. Test program requirements.
  - *Product QRE.* Responsible for specific product. Product Qualification.
  - *Materials QRE.* Quality control of incoming materials and vendors.
  - *Manufacturing/Factory QRE.* Monitors. MRB, DRB. Containment.
  - *Customer QRE.* Find customer Q&R req'ts, deal with Q&R "escapes".

Life of an Integrated Circuit

Assembly → **Shipping** → **Storage** → **OEM/ODM Assembly** → **End-user Environment**



Desktop

Shipping Shock

Temperature Cycle

Bend

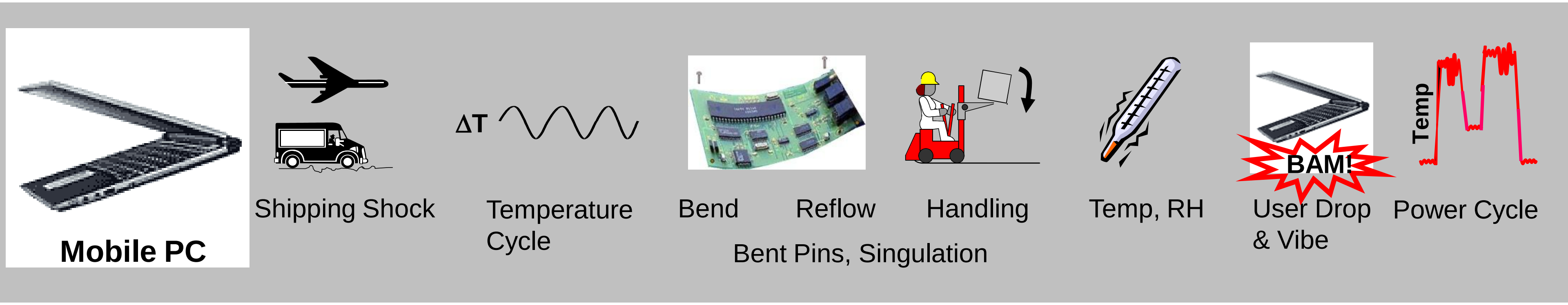
Reflow

Handling

Bent Pins, Singulation

Temp, RH

Power Cycle



Mobile PC

Shipping Shock

Temperature Cycle

Bend

Reflow

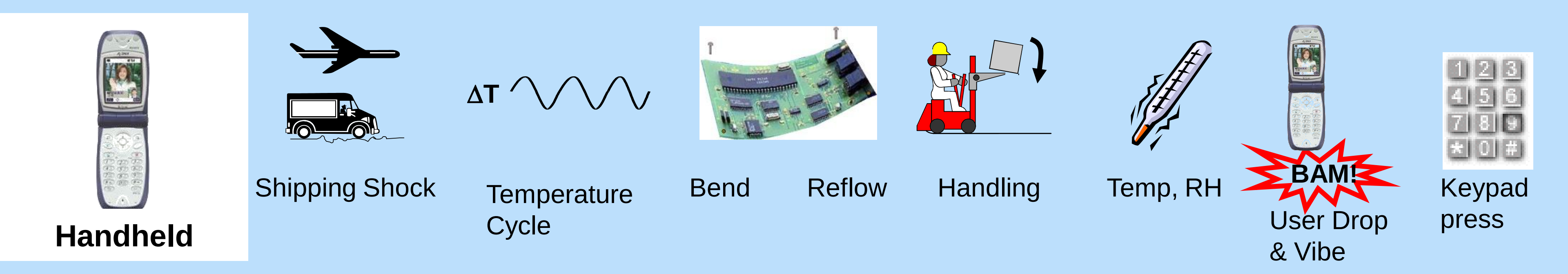
Handling

Bent Pins, Singulation

Temp, RH

User Drop & Vibe

Power Cycle



Handheld

Shipping Shock

Temperature Cycle

Bend

Reflow

Handling

Temp, RH

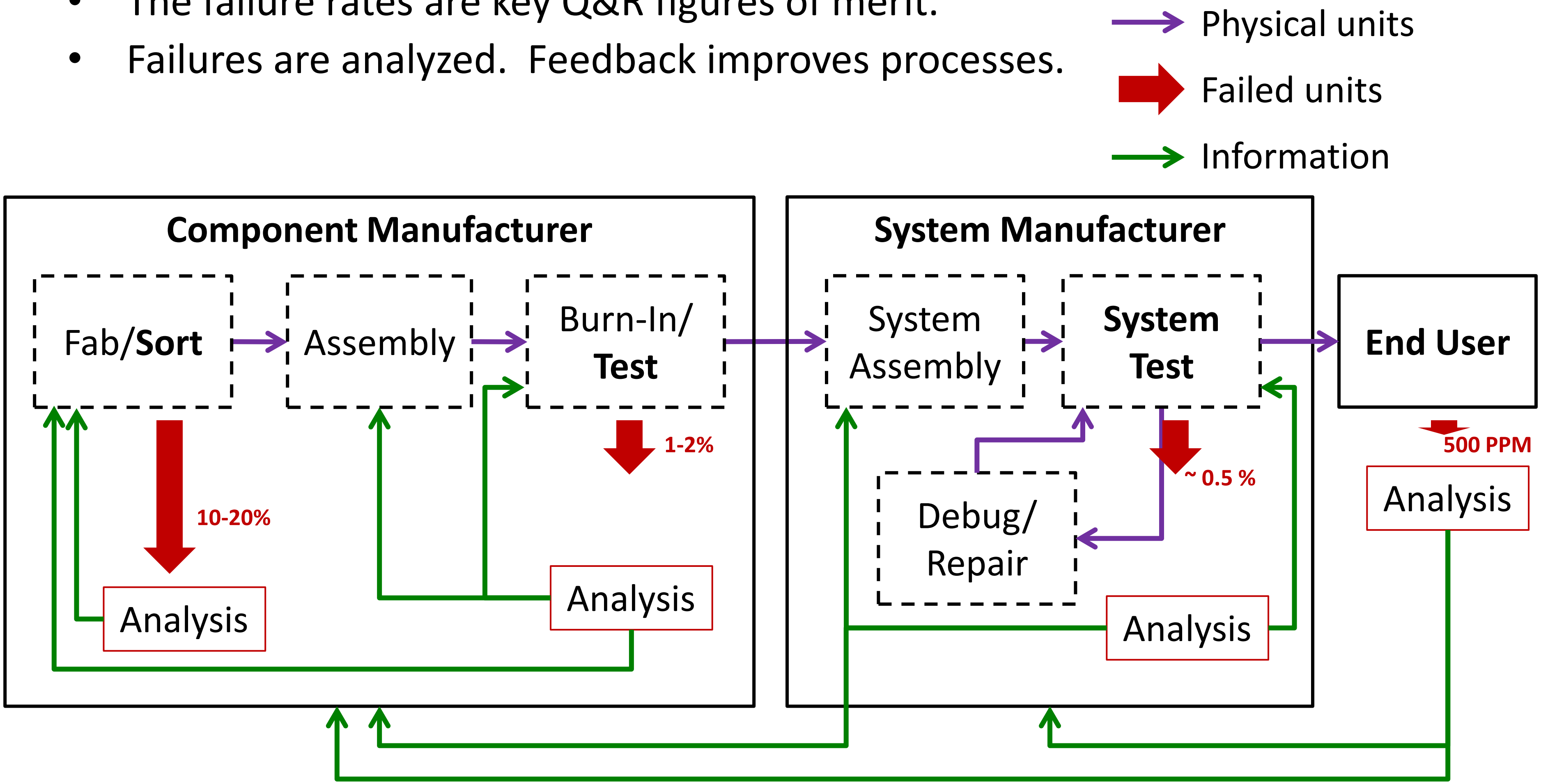
User Drop & Vibe

Keypad press

Slide by Scott C. Johnson.

Physical Manufacturing/Use Flow

- The QRE must keep in mind the entire physical life of the component.
- Component Mfr and System Mfr generates failures, as does End Use.
- The failure rates are key Q&R figures of merit.
- Failures are analyzed. Feedback improves processes.



Quality vs Reliability

- Quality.
  - Conformance to specification at the customer, usually the System Mfr.
  - Impact: Rework at System Manufacturer. Brand image.
  - Measures of Quality (Figures of Merit)
    - How (which attributes) unit fails to meet specification.
      - Eg. Out of box experience.
    - Fraction of the population failing to meet specification.
      - Eg. 2%, 500 PPM, 300 DPPM, 300 DPM.

For discussion: What "population" do we mean?

- Reliability
  - Conformance to specification usually at the End User, *through time*.
  - Impact: Warranty cost to system Mfr. Brand image of System Mfr. to End User. Brand image of Component Mfr to System Mfr.
  - Measures of Reliability (Figures of Merit)
    - How (which attributes) *and when* unit fails to meet specification.
    - Fraction of the population failing to meet specification *in a specified time interval*.
      - Eg. 1% in 7 years, 500 DPM in 30 days, 0.1% in warranty period, 10 %/kh, 100 Fits.

Measures of Reliability

- Equivalent failure rate units

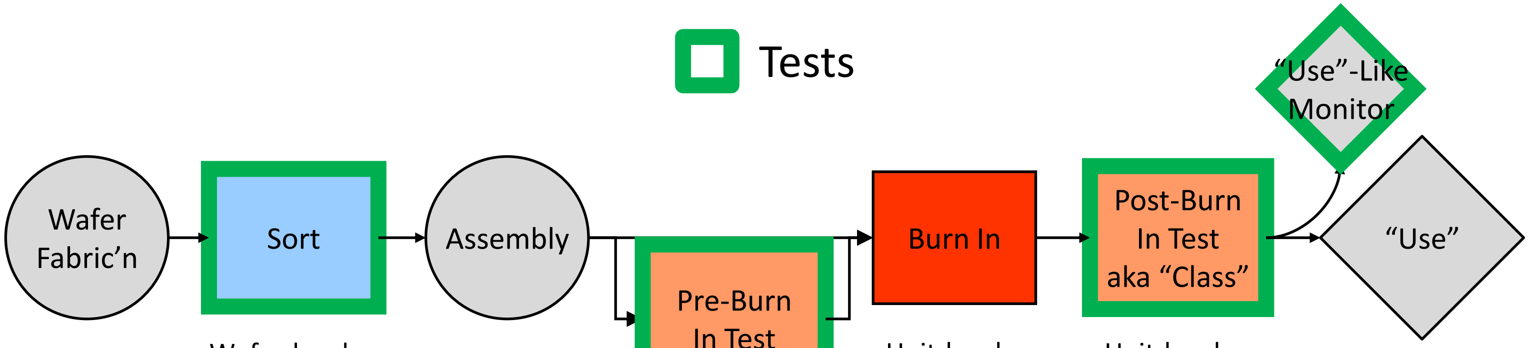
Fail Fraction per Hour	% per 1000 hrs	FIT
0.00001	1.0	10,000
0.000001	0.1	1,000
0.0000001	0.01	100
0.00000001	0.001	10
0.000000001	0.0001	1

- Conversion Factors
  - Fail fraction per hour x 10^5 = % per Khr
  - Fail fraction per hour x 10^9 = FIT
  - % per Khr x 10^4 = FIT

FITs = “Failures in Time”

Quality Assurance

- Quality assurance is achieved by thorough test.
- Test occurs throughout the manufacturing process, not just at the end.



🟩 Tests

Wafer Fabric'n → Sort → Assembly → Pre-Burn In Test → Burn In → Post-Burn In Test aka "Class" → "Use"

"Use"-Like Monitor

Sort: Wafer-level **Cold**

Pre-Burn In Test: Unit-level **Hot**

Burn In: Unit-level Stress **Very Hot**, High Voltage

Post-Burn In Test: Unit-level **Hot**

- Purpose of Test
  - Screen grossly defective and out-of-spec parts.
  - Classify parts into various speed, power, etc. bins.

Manufacture 1.3M Die

Screen out the Bad Die (defects 300K)

Speed Bin the Good Die

Q&R FOMs and Targets

- Measures of quality and reliability called Figures of Merit (FOMs) are compared with “Targets” (sometimes called “Goals”).
- Comparison of FOMs with Targets determines whether or not a process or product passes or fails a Process Certification or Product Qualification.
  - Targets are usually “do-not-exceed” limits for FOMs.
- Targets are set at the highest corporate level based on Cost models, Competition, Brand image.
- Some Targets are internal and highly proprietary (eg. Yield Loss).
- Other Targets are published to the customers and are highly visible anyway (eg. shipped DPM).
- Typical Targets
  - Yield Loss < 10-20%
  - Class < 1-2 %
  - Customer Line Fallout < 500 DPM
  - Early Life Reliability < 500 DPM, 0 – 30 days.
  - Warranty < 1%, within warranty.
  - End-of-Life < 3%, 0 – 7 years

Not representative of any particular product.

Reliability Goals from ITRS 2009

http://www.itrs.net/reports.html

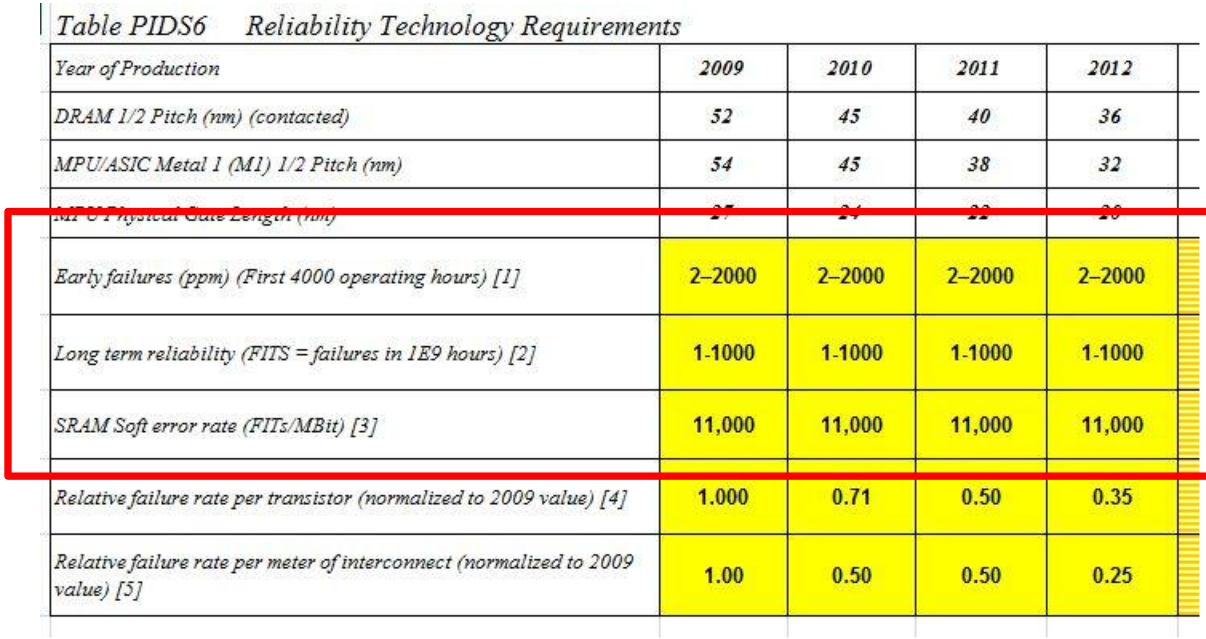


Table PIDS6 Reliability Technology Requirements

Year of Production	*2009*	*2010*	*2011*	*2012*
DRAM 1/2 Pitch (nm) (contacted)	*52*	*45*	*40*	*36*
MPU/ASIC Metal 1 (M1) 1/2 Pitch (nm)	*54*	*45*	*38*	*32*
MPU Physical Gate Length (nm)	*27*	*24*	*22*	*20*
Early failures (ppm) (First 4000 operating hours) [1]	2–2000	2–2000	2–2000	2–2000
Long term reliability (FITS = failures in 1E9 hours) [2]	1-1000	1-1000	1-1000	1-1000
SRAM Soft error rate (FITs/MBit) [3]	11,000	11,000	11,000	11,000
Relative failure rate per transistor (normalized to 2009 value) [4]	1.000	0.71	0.50	0.35
Relative failure rate per meter of interconnect (normalized to 2009 value) [5]	1.00	0.50	0.50	0.25

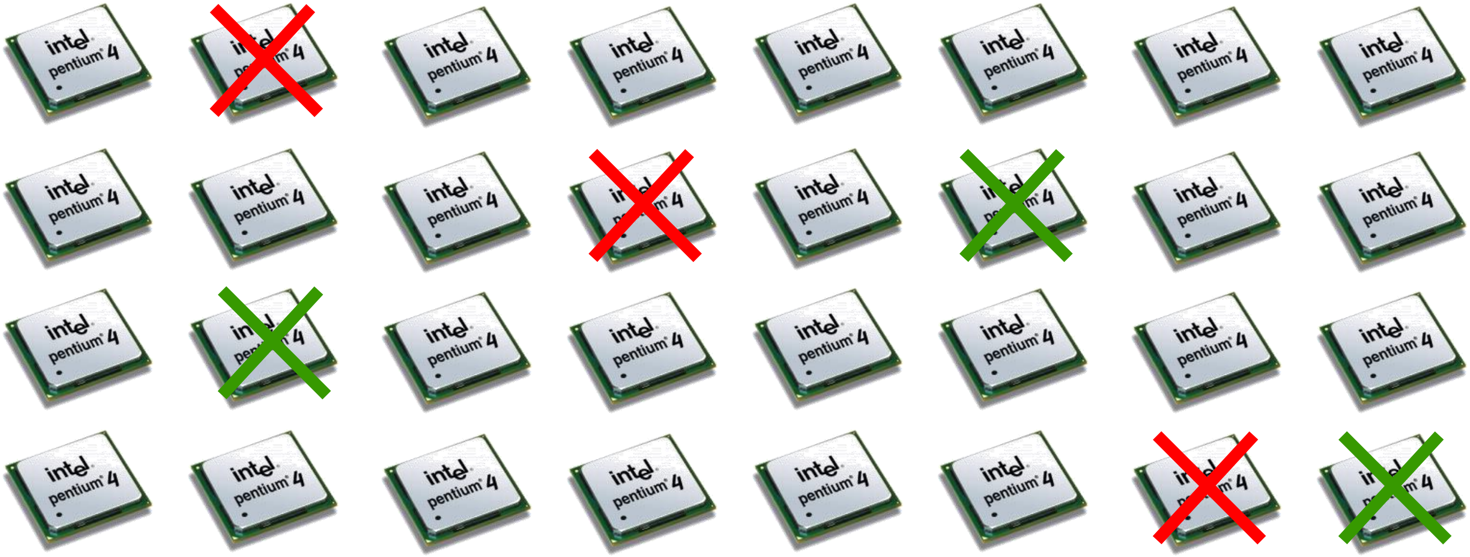
Infant Mortality

Wear-out

Constant fail rate

Reliability

The Reliability Problem



- Quality fails can be handled by thorough testing
- Reliability is harder because the fails come *long* after we’ve sold the product
  - How can we tell which parts are *going to fail* in the future?

The Reliability Solution

- The answer is that we must do research and determine
  - How the parts fail (the fail ***mechanisms***)
  - What ***stresses*** made the part fail
- Then we must
  - Design our product so that none of the fail mechanisms are activated by the stresses encountered during normal use
  - Specify those use conditions clearly
  - Test our product under *accelerated stress* conditions

Understanding Reliability: A Keyboard

- How might a keyboard key fail? (***mechanisms***)
  - Material that gives tactile “click” might fatigue and break
  - Electric contacts might corrode or become blocked with dirt
- What might cause these fails? (***stresses***)
  - Being pressed too many times (wearout)
  - Heat, humidity, dust, dirt, spills, being pressed too hard
- How can we test a key’s entire life? (*stress test*)
  - Use a machine to press it 1,000,000 times
  - Before that, heat it and shake it with dirt and water
- How can we make it more reliable? (*design for rel.*)
  - Find what breaks and make that (and only that) stronger

Reliability Example: Aircraft Reliability

- De Havilland Comet was an early commercial jet
- A few crashes were initially unexplained
- Thorough research led to understanding of metal fatigue (fail mechanism) from cabin pressurization (stress)
- Great 1-hour video (TV show) about it:
  - http://www.youtube.com/watch?v=_3JZ3wHlgvI

Reliability Assurance

The stresses and fail mechanisms for integrated circuits are different, but the concepts are the same:

- **Stresses:** voltage, temperature, current, humidity, radiation, temperature cycling, mechanical stress
- **Mechanisms:** transistors (degradation), interconnects (cracking), package (corrosion, fatigue)

Reliability is assured by a qualification process, where statistical samples of products are stressed to simulate a lifetime.

A burn-in system and HAST system perform stress tests on chips

We will now give an example of the sort of exercise we will do most days in this class:

Monte Carlo Methods

What is Monte Carlo?

Monte Carlo, Monaco, Europe

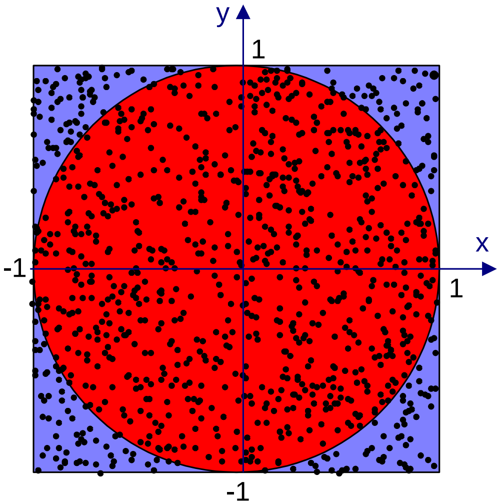
- Answer: A famous casino.
- Monte Carlo (MC) methods are numerical calculations using random numbers

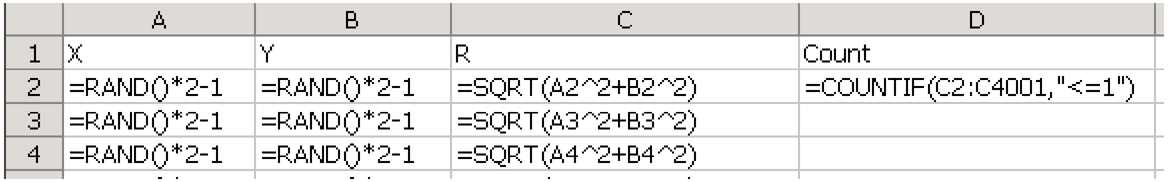
What Can Monte Carlo Do?

- Answer: Give approximate numerical solutions to problems we can’t solve exactly
- Best suited for:
  - Distributions
  - Integrals (areas under a curve)

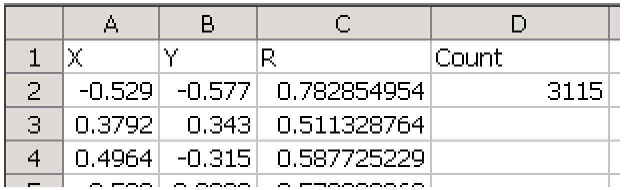
  when we have
  - Many parameters (= many dimensions)
  - Complicated or non-analytic functional forms
- Many simulations of the manufacturing process are ideal for MC

Finding an Area Using MC





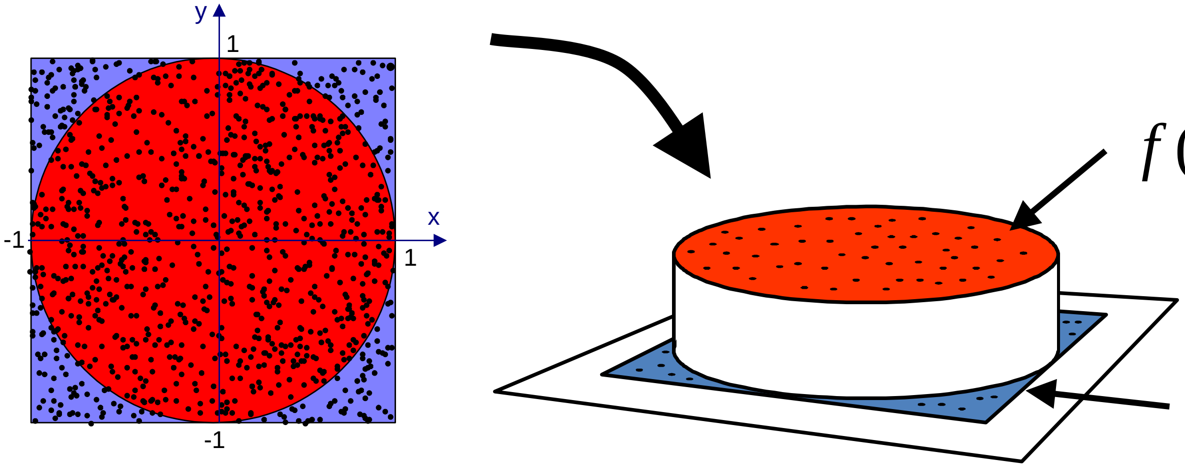
	A	B	C	D
1	X	Y	R	Count
2	=RAND()*2-1	=RAND()*2-1	=SQRT(A2^2+B2^2)	=COUNTIF(C2:C4001,"<=1")
3	=RAND()*2-1	=RAND()*2-1	=SQRT(A3^2+B3^2)	
4	=RAND()*2-1	=RAND()*2-1	=SQRT(A4^2+B4^2)	



	A	B	C	D
1	X	Y	R	Count
2	-0.529	-0.577	0.782854954	3115
3	0.3792	0.343	0.511328764	
4	0.4964	-0.315	0.587725229	

- Here is a MC example: find the area of a circle.
  - For 4000 random points, area=3.115
  - Actual area = π = 3.141
- Can be done using
  - Excel (shown here, formulas and results)
  - VB, C++, or any programming language
  - JMP or many other math-related software programs

Thinking Like an Integral



$$f(x,y) = \begin{cases} 1 & \text{inside circle} \\ 0 & \text{outside} \end{cases}$$

V = blue square = 4

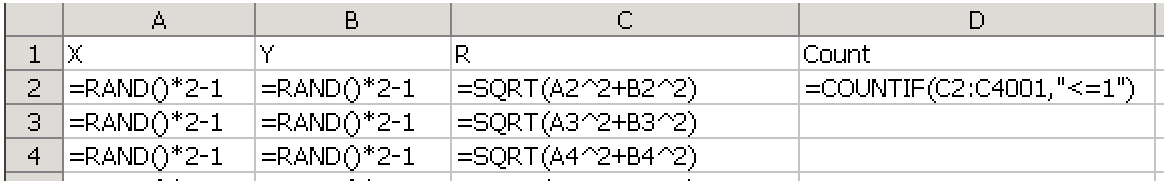
- Many of our simulations can be interpreted as integrals (area under a curve)
- The area under this function is $\int f \; dV = V \langle f \rangle$

Angle brackets are an average, $\langle f \rangle = \frac{1}{N} \sum_{i=1}^{N} f(x_i)$

Exercise 1.1

- Do a Monte Carlo calculation of Pi as shown in the previous slide. Use 4000 samples.
- Be prepared to give your numerical answer (*x* points out of 4000 are in the circle) in class.
- Turn in your spreadsheet by email before beginning of class 1 week from today.

Exercise 1.1 Solution



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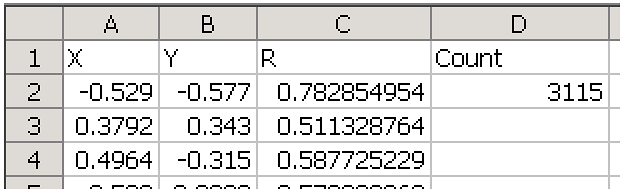

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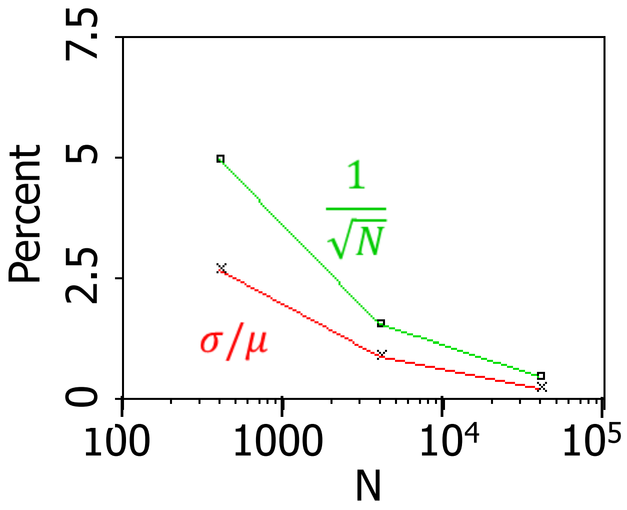
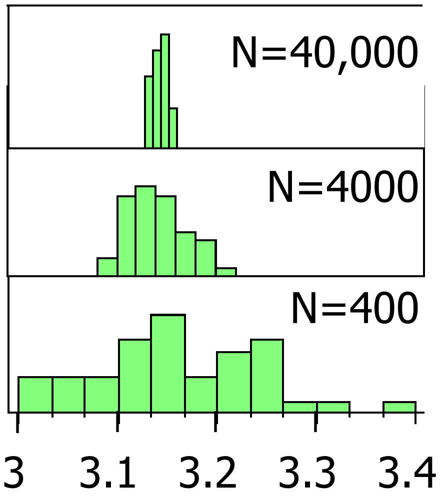
- Already shown two slides back.

Distribution of Answers

- Collect and plot answers from everyone in class

Accuracy of MC





σ/μ=0.22%

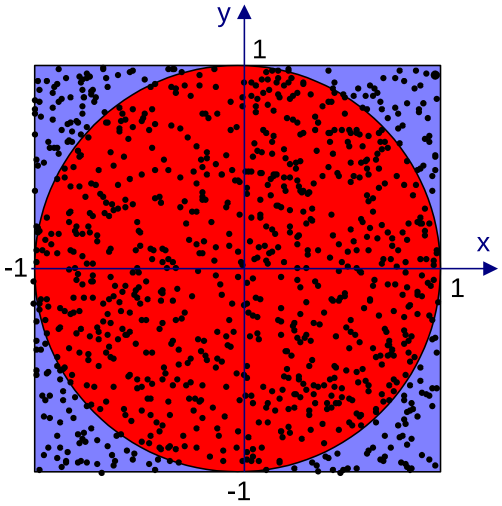
σ/μ=0.88%

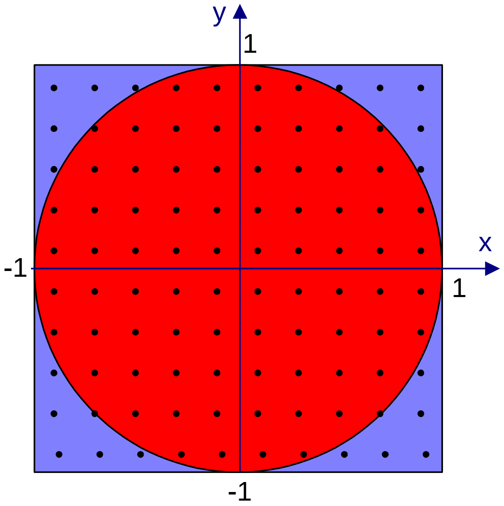
σ/μ=2.7%

σ=standard dev
μ=mean
40 trials per N

- Calculated precision of MC integral: $V\sqrt{\frac{\langle f^2\rangle - \langle f\rangle^2}{N}}$
- “Experimentally” verified
- Precision depends on the number of samples N
  - Accuracy of a MC simulation depends on many things
- *Rule of thumb:* precision is $\sim \frac{1}{\sqrt{N}}$

When to Use MC





- For 2D functions (or shapes, like this), a grid technique is better
  - No statistical uncertainty
- For high-dimensional functions (many parameters), MC is the only practical technique
  - Example: 20 parameters with a grid of 10 points per parameter
  - That is 10^{20} calculations
  - For a fast computer, 300M calcs/sec, still take 10,000 *years* to evaluate
- Bottom line: Use MC when you have many parameters

The End