16.682 - Prototyping Avionics
Spring 2006

Instructor

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DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

Outline

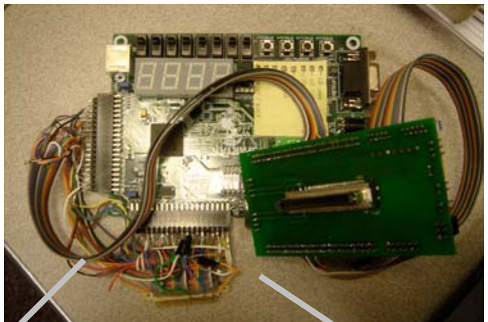
- **Class organization**
  - Motivation, objectives
- **(Re-) Introduction to Design**
  - Requirements, Design Processes, Why “Prototype” now?
- **Subject overview**
  - Overview of EE concepts
  - Show & tell of software we will use

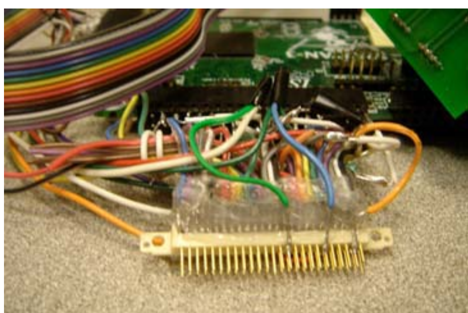
“The scientist seeks to understand what is; the engineer seeks to create what never was”

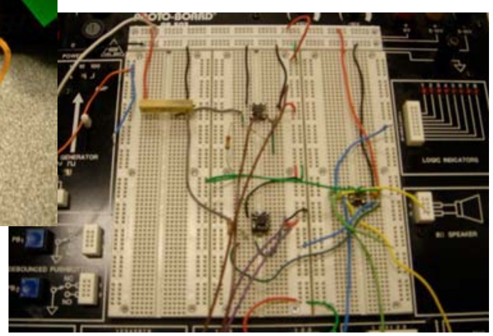
– Von Karman

Motivation

- **Before**

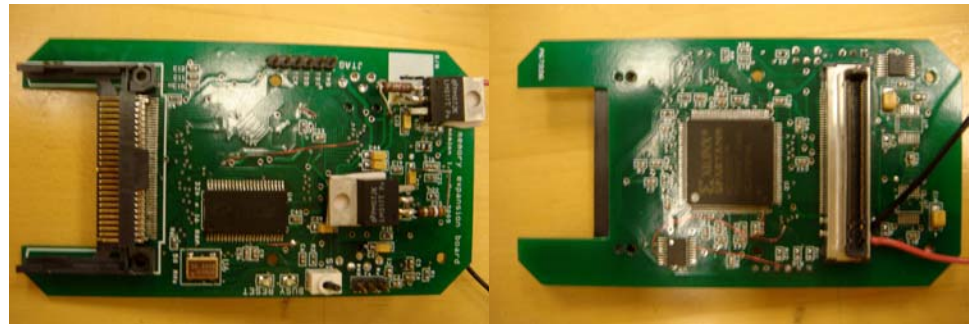






PCB ~$2-5K

- **Now**



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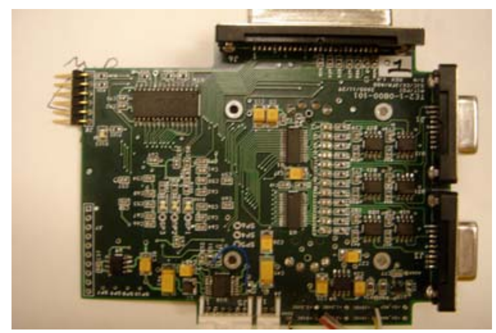


~$500

Objectives

- **Bottom line:**
  - **Learn to make printed circuit boards**

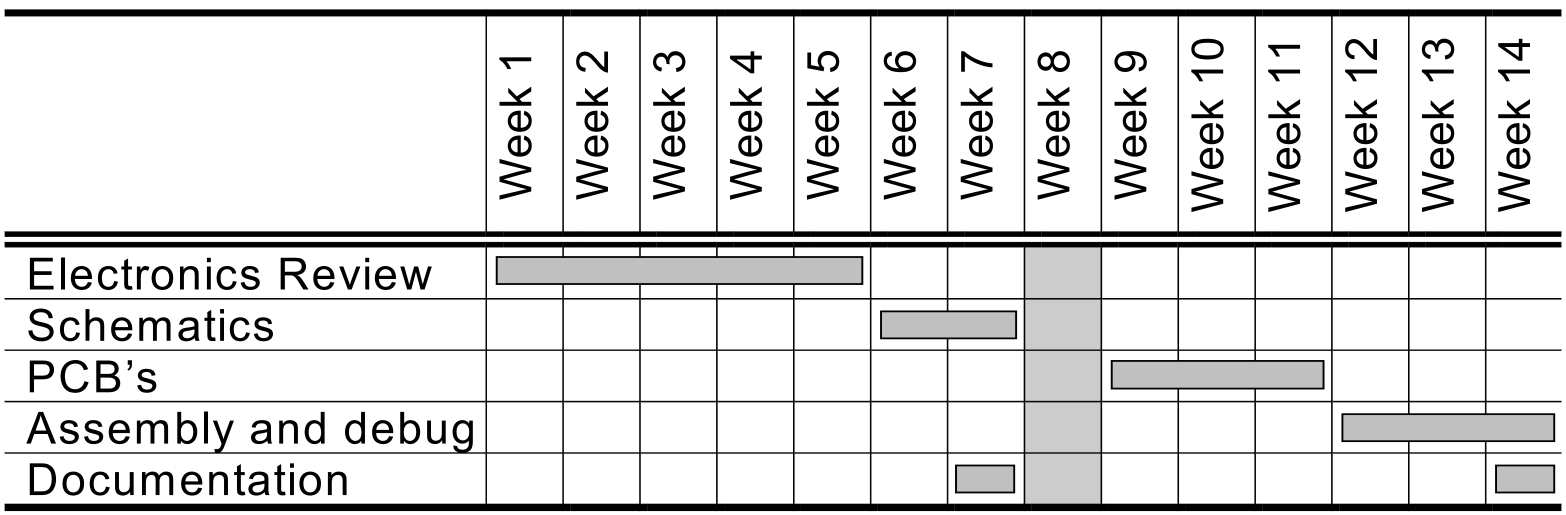
- **More in depth:**
  - **Identify the main components of an avionics prototype**
  - **Use schematic capture software to create detailed schematics**
  - **Use PCB layout programs to create avionics boards**
    - **Assembly avionics PCBs**
  - **Understand the test and debug processes for avionics**

Class Organization

- "Prototype" class
  - Builds upon the "rapid prototyping" of mechanical hardware (by Oliver deWeck) given during IAP
  - First class to introduce prototyping of PCB's at MIT Aero/Astro
- 6 unit class
  - 2-2-2
    - 2 hour of lecture practically every week
    - you are expected to spend two hours in lab during the PCB design phase
    - about 2 hours of homework during the first month, then documentation of project

Class Overview

- **Two main sections of the class**
  - **1) Electronics review**
    - **4 weeks to review analog and digital electronics**
    - **Will reverse-engineer circuits and create some of our own**
  - **2) PCB design**
    - **Schematic capture - how your circuit works, captured electronically**
    - **PCB layout - actually "drawing" how the printed circuit board looks like**



Grading & Deliverables

- **Based on the two parts of the class**
  - **4 problem sets, total 30%, of electronics review**
    - **Will directly cover the topics of that week**
  - **50% will be the schematics and layout projects**
    - **Will incrementally build on the**
  - **20% on documenting the projects**
    - **Creating a "data sheet" of the project and a final report**

Criteria	Weight
Homework	30%
Documentation: functional	10%
Schematic	25%
Layout	25%
Documentation: test, debug, results	10%

Resources

- Textbook
  - None required - we'll learn to *find* and read data-sheets
- Laboratory
  - Main area: (through April)
    - All computers have schematic and layout software
      - Altium Designer
  - Assembly area: Gelb Lab (once our boards are made)
    - Assembly (soldering) and debugging of boards
  - Demo area: Space Systems Lab
    - Microscope use
    - Complex embedded systems demo

(Re)Introduction to Design

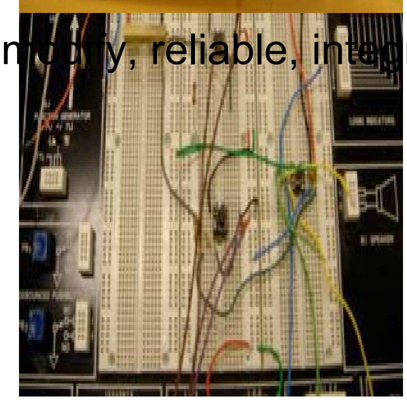
reproduced with permission, Oliver deWeck

Design: an iterative process

1. Define Requirements
2. Create/Choose Concept
3. Perform Design
4. Analyze System
5. Build Prototype
6. Test Prototype
7. Accept Final Design

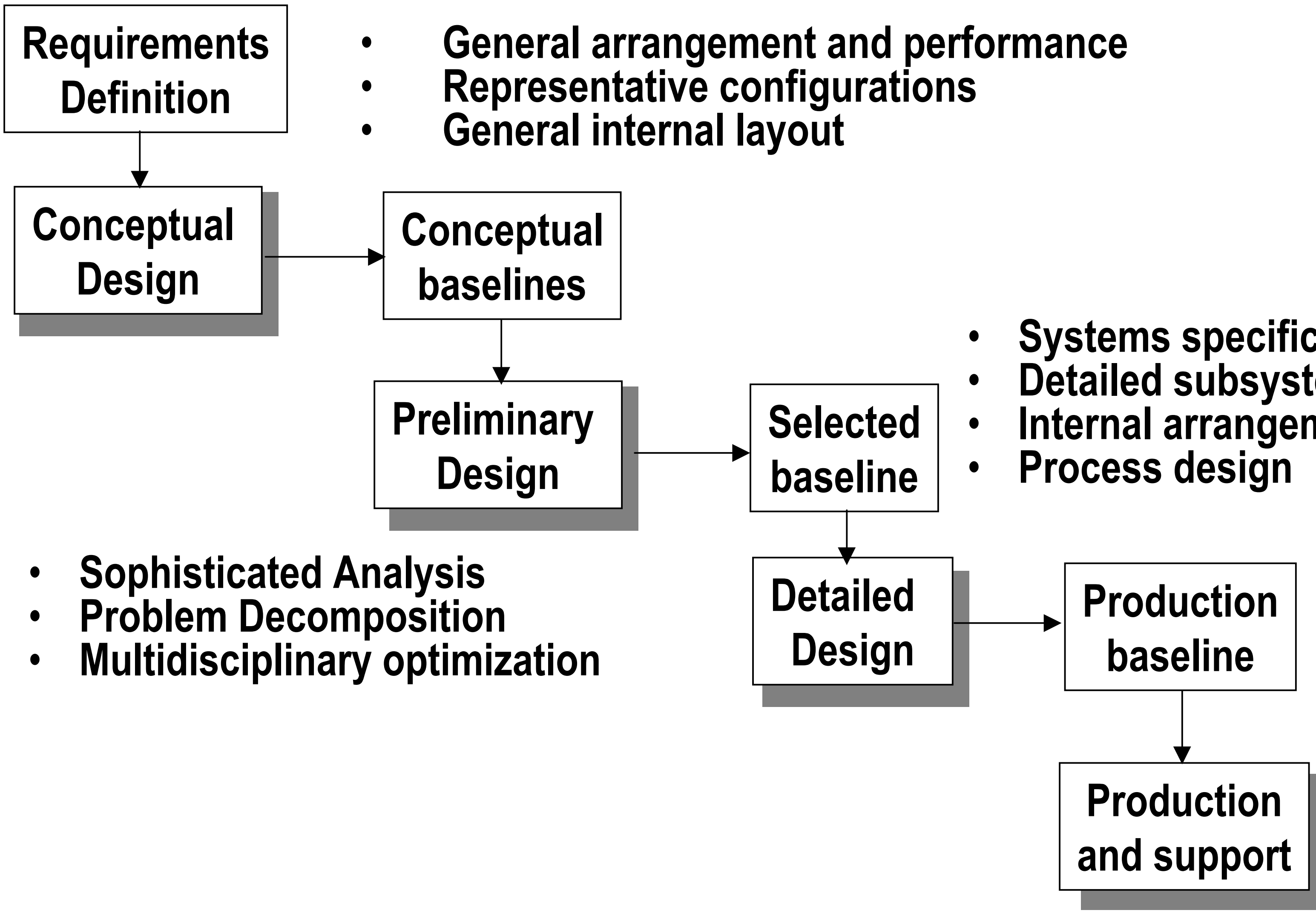
easy to modify, unreliable, stand-alone

can modify, reliable, integrated



hard to modify, very reliable, final

Typical Design Phases

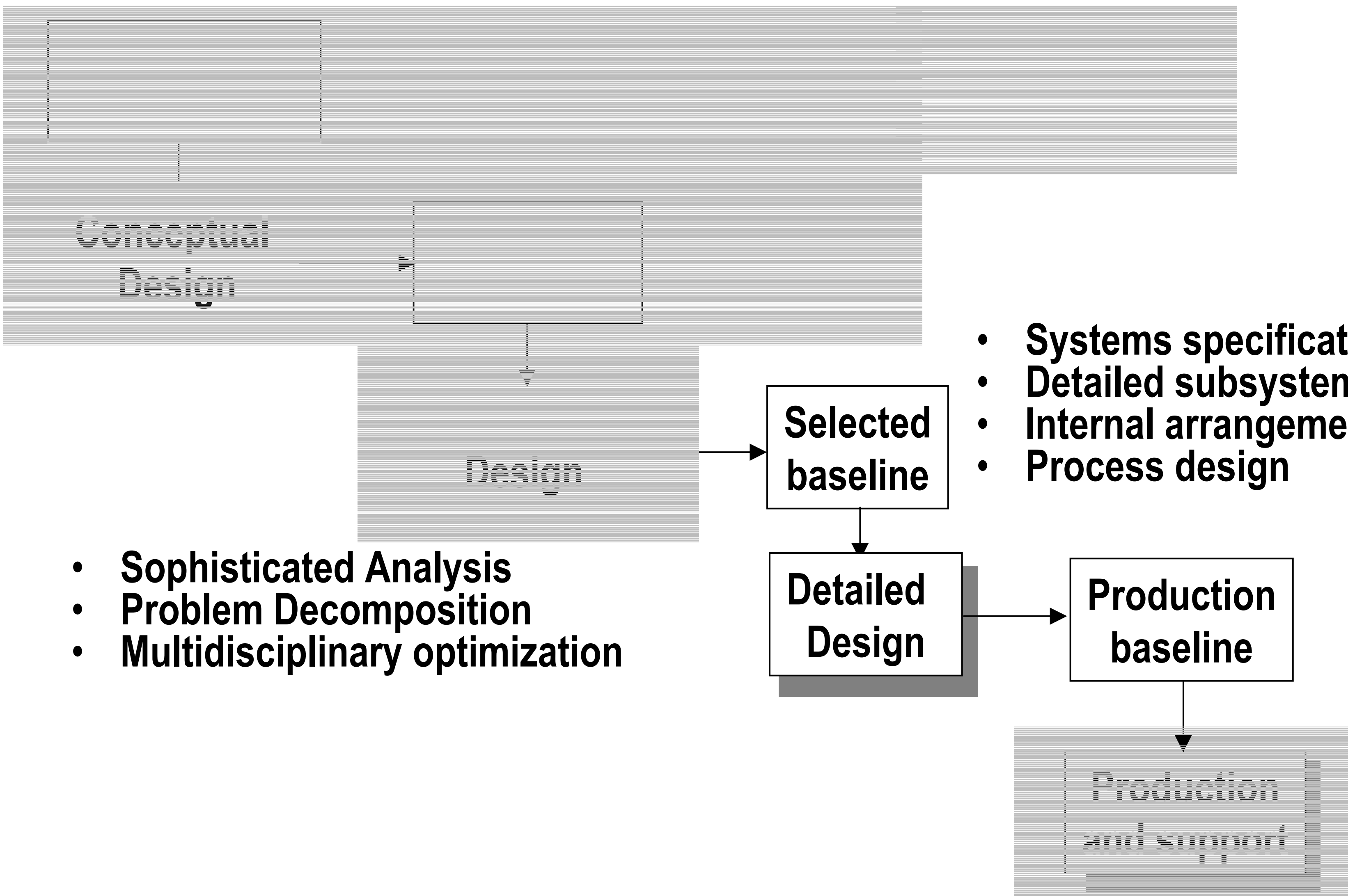


- General arrangement and performance
- Representative configurations
- General internal layout

- Systems specifications
- Detailed subsystems
- Internal arrangements
- Process design

- Sophisticated Analysis
- Problem Decomposition
- Multidisciplinary optimization

Typical Design Phases



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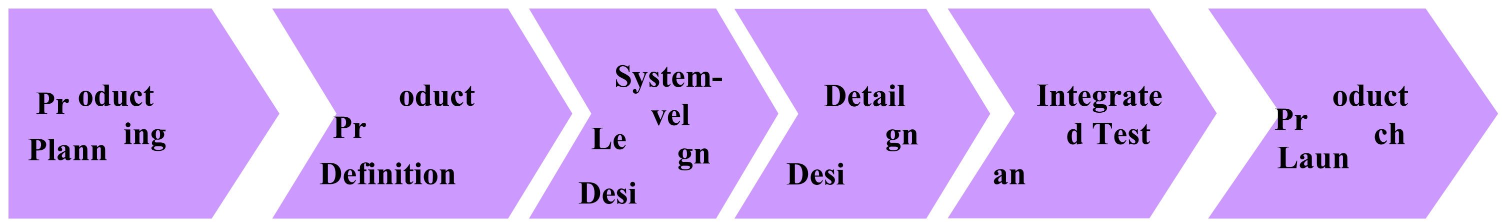
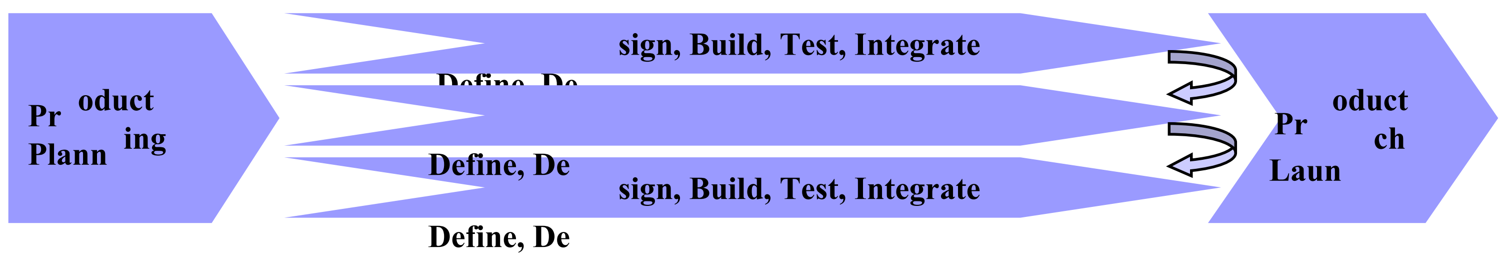
Phased vs. Spiral PD Processes

Phased, Staged, or Waterfall PD Process
(dominant for over 30 years)

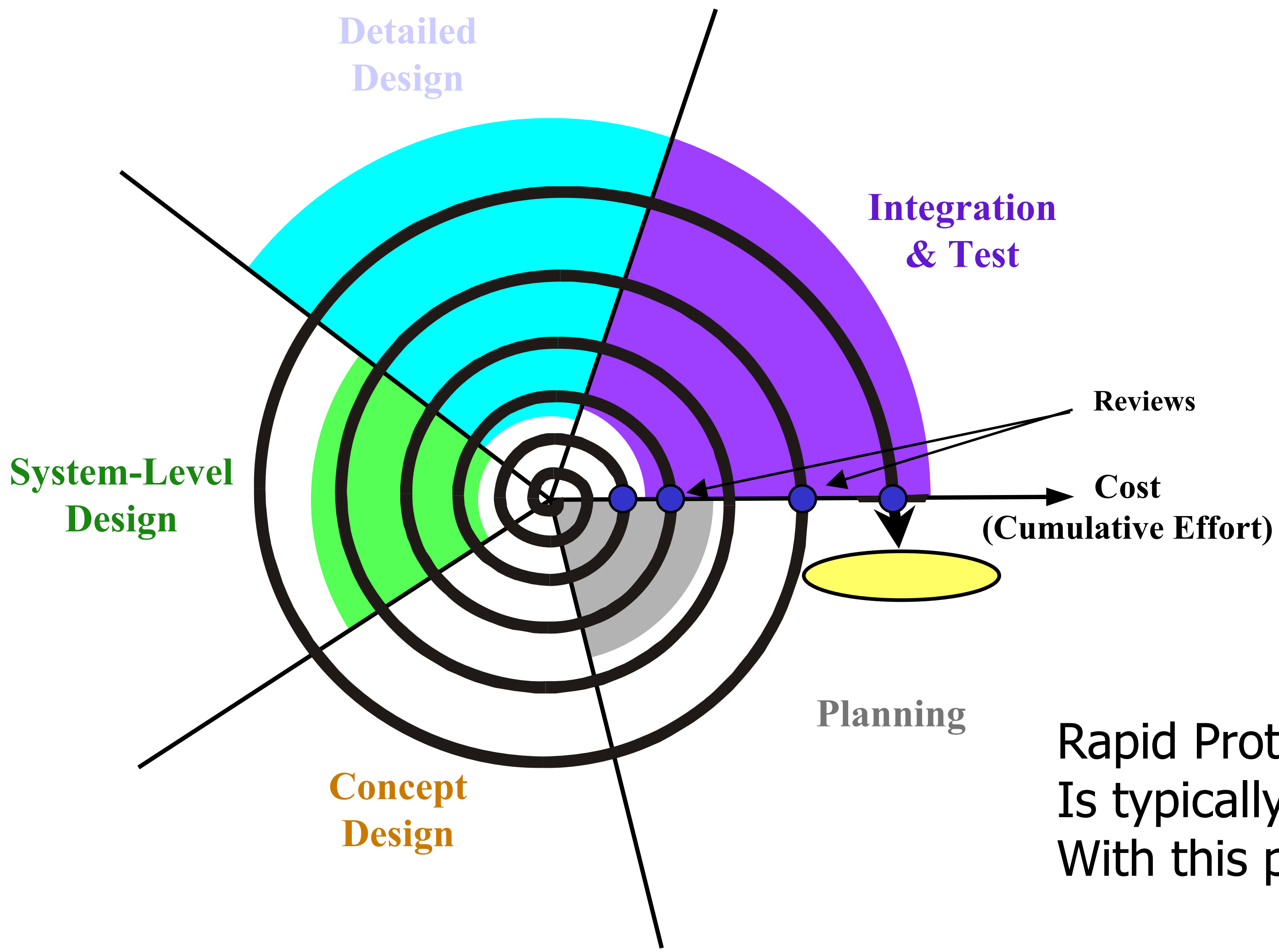


Spiral PD Process
(primarily used in software development)



- **Process Design Questions:**
  - How many spirals should be planned?
  - Which phases should be in each spiral?
  - When to conduct gate reviews?

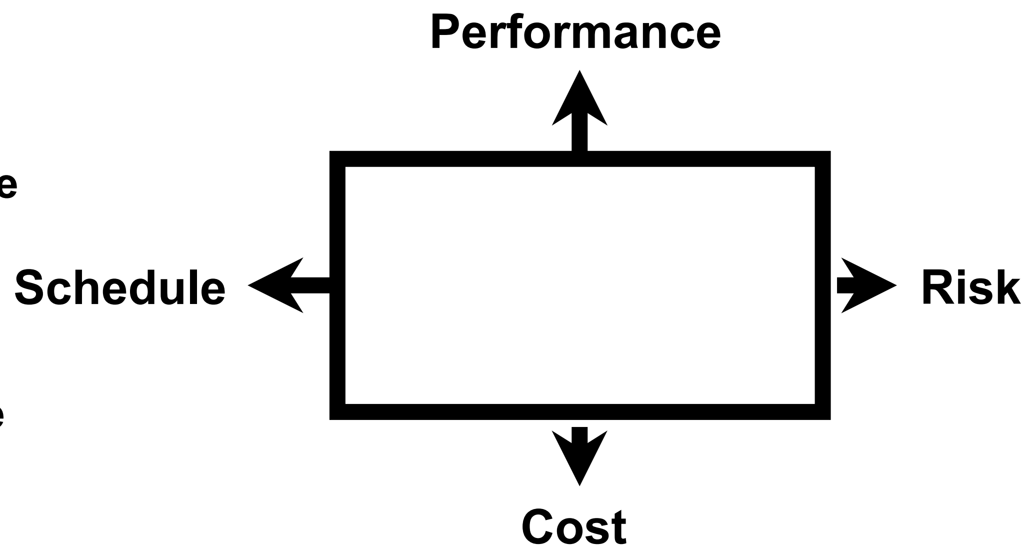
Spiral PD Process



Rapid Prototyping
Is typically associated
With this process

Basic Trade-offs in Product Development

- **Performance**
  - ability to do primary mission
- **Cost**
  - development, operation life cycle cost
- **Schedule**
  - time to first unit, production rate
- **Risk**
  - of technical and or financial failure



Where do the different phases of avionics design fit in these trade-offs?

Ref: Maier, Rechtin, "The Art of Systems Architecting"

Class Content

Review of E&M

- **Remember 8.02?**
  - **Analog electronics ultimately go back to the basic concepts of E&M:**
    - **Voltage**
    - **Current**
  - **Power system design and analysis depends on E&M concepts:**
    - **Inductance**
    - **Capacitance**
    - **Watts**
  - **We'll review:**
    - **$V=IR$**
    - **$P=IV=I^2R$**
    - **$I = CdV/dt$**
    - **$V = LdI/dt$**

Discrete Components

- Discrete components are some of the most basic parts of a circuit
  - Usually passive
  - Normally one component per package
  - Implement basic E&M
- Include:
  - Resistors, capacitors, inductors, and diodes
  - First and second order systems created with passive components
  - Emphasis on voltage dividers and low-pass filters
- Also some active elements: amplifiers
  - Assume an ideal amplifier
  - Review general equations to implement different types of common circuits

Transistors

- These days each microprocessor contains millions of transistors…
- But what does a single transistor do?
  - Its essential to understand what a single transistor does to understand better how many analog *and digital* circuit operate
- There are many types of transistors, most importantly
  - NPN/PNP
  - MOSFETs
- Transistors have two behaviors: transient and saturated
  - Analog circuits operate in the transient behavior
  - Digital circuits saturate transistors
  - *We'll emphasize the use of transistors in digital electronics*

Power Components

- You have a single AAA 1.5V battery… how do you power a 5V microcontroller?
  - Remember that E&M has a lot to do with power: RLC circuits can create a “voltage pump”
- You have 120Vac and need to power a 5V micro-controller, how?
  - Remember discrete components: diodes and capacitors help you create a DC signal out of an AC signal
  - Remember E&M? Voltage transformers use E&M to swap voltage for current
- I have 5V and I need 2.5V, how do I do that?
  - Could use a resistor-based voltage divider, a linear regulator, or a switching regulator… which one do I choose?

Digital Components

- The most basic block of a digital system is called a "gate"
  - and, or, nor, xor
  - Normally specified using "truth tables"
- Gates are put together to create more complex parts
  - multiplexers
  - registers
  - latches, and flip-flops
- Tens, hundreds, even thousands of these make microprocessors and other parts
- BUT individual blocks are still needed from time to time independently, so we need to know what their basic functions are
  - One bit at a time

Digital Thinking

- **Digital systems work with many bits at a time, so its important to understand how to work with many bits at a time:**
  - **Bit groupings: bit vs. nibble vs. byte vs. word**
  - **Notations: octal vs. decimal vs. hexadecimal**
  - **Operations: bitwise vs. byte/word operations**
  - **Data types: how do computers *represent* data**
- **Its also important to understand how computers maintain the data:**
  - **Stacks and queues**
  - **Pointers**
  - **Memory operations**

Processors

- Processors can be very simple (e.g. an 8-bit PIC) or extremely complex (e.g. a dual-core 65bit Intel)
  - Embedded processors are usually considered for low-power consumption (which means low heat), so we'll talk about simple processors in general
- General purpose processor architecture
  - Processing unit
  - Program memory and stack
  - Data memory
  - Peripherals
  - Interfaces
  - Language?
    - Assembly
    - C, C++
    - ADA
- To really learn processors you'll have to take 6.115 for now

Interfacing Analog & Digital

- **You have a 32-bit processor and a temperature sensor that connects to a resistor, what do you do?**
  - **ADC: analog to digital conversion**
  - **What do you need to learn:**
    - **Sample rates(aliasing), discretization, bit-depth**
- **The processor calculates the motor needs to run at 40% of its maximum speed, how do you tell it to do it?**
  - **Multiple options:**
    - **Pulse-width modulation + amplifiers**
    - **DAC: digital to analog conversion + amplifiers**

Schematics

- **Start basic:**
  - **Single-page schematic with pre-existing components**
- **Add complexity:**
  - **Define your own parts that are not found in the included libraries**
- **More complexity:**
  - **Larger schematic that requires multiple pages**
- **Re-simplify?**
  - **Group repeated circuits into "multiple channels" schematics**
- **Finalize**
  - **Number all the components (automatically, of course) and check for errors**

Layout

- What is a <u>p</u>rinted <u>c</u>ircuit <u>b</u>oard?
  - All of you have seen one by now, but what are its parts?
- You designed your circuit, but exactly which parts do you use?
  - Surface mount vs. through-hole components
    - Package definitions
  - Annular rings, clearance, and thermal relieves
  - Hole sizes, drills, and mounting holes
- Routing a board
  - Manual routing: take care of noise, ground lines, power lines
  - Automatic routing: when to use it
- Finishing the board
  - Error checking, plotting/printing, file output, manufacturing details

Documentation / Assembly

- By now you will have seen many datasheets…
  - Time to create your own
- Describe the functionality of the avionics board
  - Timing diagrams
  - Truth tables
  - Ratings
  - Plots

- Have all the parts?
  - Time to solder!
  - Soldering techniques (microscopes are not only for bio)
  - Part management
    - What happens when the part does not fit?

Debugging

- The first time you power up your PCB everything will work perfectly, right?
  - power check
  - critical net check
  - assembly in stages
- How do you debug?
  - Oscilloscope operation
  - Signal generators
  - Logic analyzer introduction

What's next?

- Fill out the questionnaire at the end of the syllabus handout
  - Think if you have any specific avionics in mind for the class
- Tell others about the class
- Problem Set 1 will be out until Monday Feb 13th, will be due Tue Feb 21st (Monday schedule)
- See you Monday!