EE 4323 – Industrial Control Systems
Module 1: Introduction

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Introduction and "Big Picture" – Outline

- Course Conduct
- My background
- Philosophy & Objectives
- Outline & Guided Tour
- "Big Picture" Material

Course Conduct

- Standard lecture format – *with questions encouraged!*
- Textbook – none; I will email copies of my slides; I'll distribute handouts → book chapters, papers, *et cetera*.
- Resources (borrow from me):
  - Norman S. Nise, *Control Systems Engineering*, 4^{th} Ed., John Wiley & Sons, 2004.
  - C. D. Johnson, *Process Control Instrumentation Technology*, Prentice Hall, Fifth Edition, 1997 (emphasis on process control)
  - C. L. Nachtigal, *Instrumentation & Control - Fundamentals and Applications*, John Wiley & Sons, 1990 (practical / encyclodedic)
- Evaluation: Homework → 25%, Mid-term → 30%, Final exam → 45%. **Final letter grades will be based on competency, not a predefined numerical scale.**
- Homework should be done using MATLAB to the extent possible; hand in scripts, programs and macro listings, plots...
- Exams will be *closed-book* except for **one** page of notes (both sides; 2 pages for the Final); basic scientific calculators allowed but no programmable calculators/laptops.
- A **passing grade** on homework is required for official audit.
- Office hours: MWF 13:00 - 15:00; short/simple e-mail questions will be answered promptly. I can be available other times, but during office hours you are Priority # 1. **The sooner you ask for help, the better!**

Philosophy & Objectives

Philosophy:

- Emphasis on solving *practical* problems
- Emphasis on *thinking* and promoting *insight*
- Emphasis on breadth of problems and approaches
- Emphasis on multidisciplinary applications
- Emphasis on the *hard parts*
- No more low-level detail than necessary

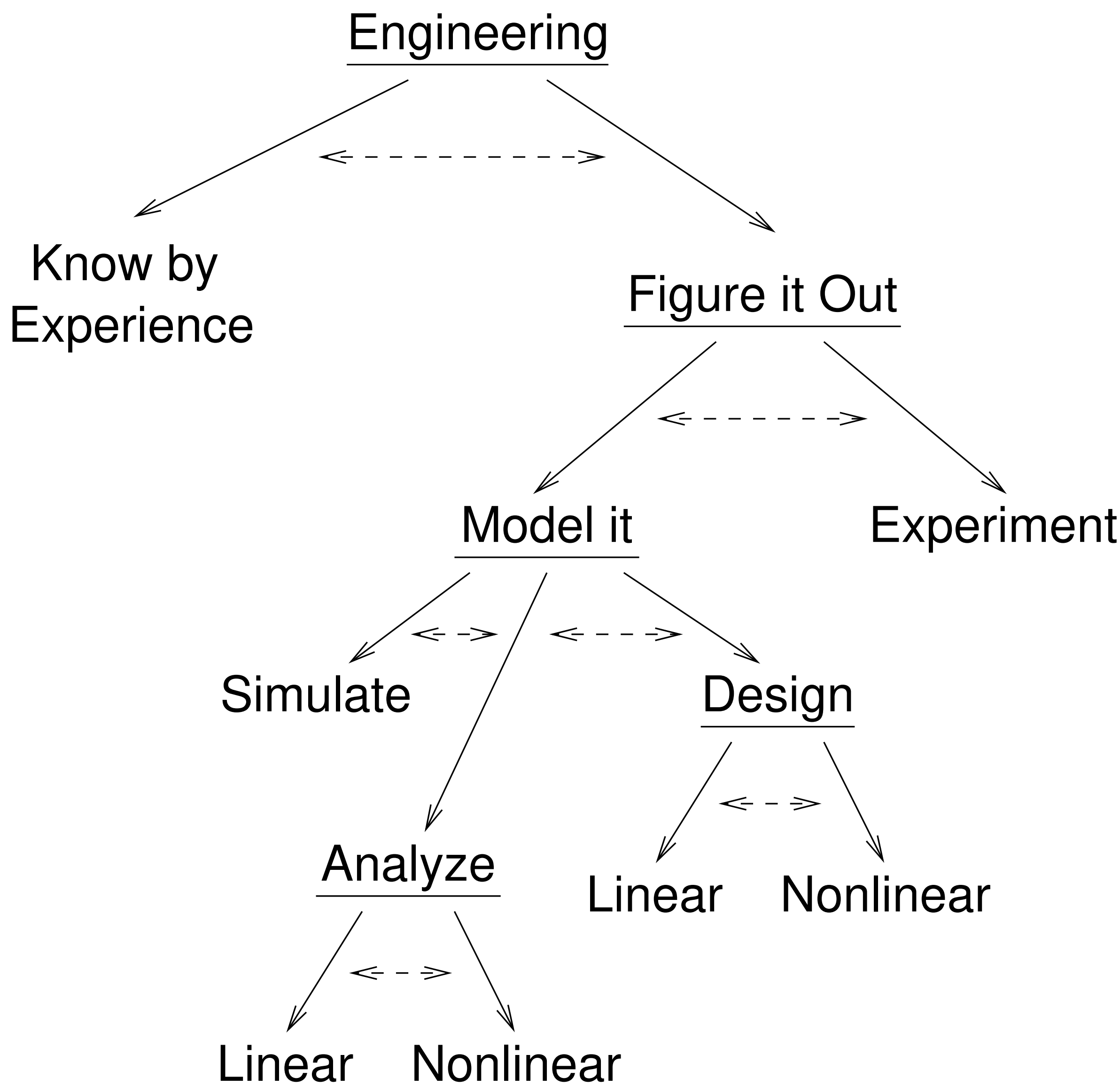
Fundamental Goals of Systems & Control:

- Figure out how it works
- Figure out how to make it work **better**

Objectives:

- To make EE 4323 and a career in systems & control interesting and attractive
- To give you the knowledge and insight needed to be the "key systems engineer" that industry needs

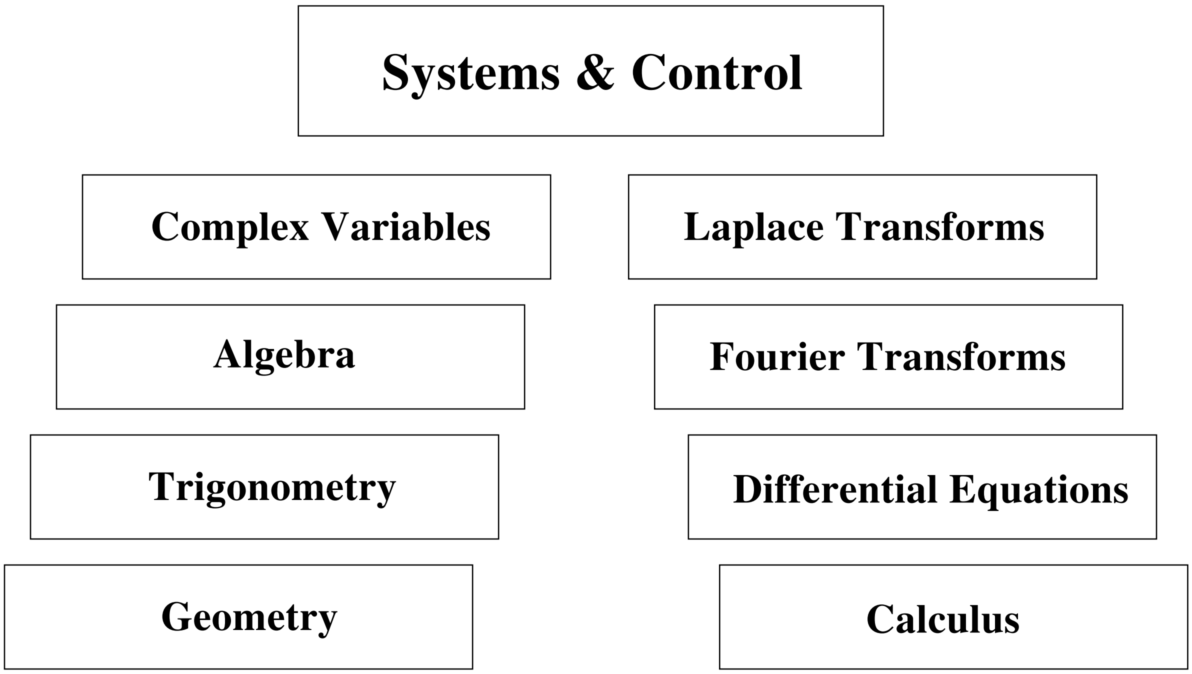
What's it All About?



As you proceed, what you learn from **"Figure it Out"** is transferred to **"Know by Experience"** ...

What's It All About? (Cont'd)

Finally, in systems and control you will be using almost all the math you ever learned . . .



. . . plus physics, circuits, mechanics, chemistry, thermodynamics, . . . Specifically, we will use:

- Physics, geometry, algebra, etc. to produce math models of systems to be controlled
- Differentiation to produce linearized differential equation models for analysis and design
- Laplace to time domain relationships (e.g., relate poles of $G(s)$ to transient response and stability)
- Frequency domain to time domain relationships (e.g., relate the shape of the open loop frequency response to that of the closed loop, and relate that to time domain specifications)

My Background

- PhD, Yale University, Absolute Stability Theory
- Taught EE for 3 years (systems and controls), Indian Institute of Science, Bangalore, India → book on Absolute Stability
- The Analytic Sciences Corp. → R&D for military applications (missile performance, aircraft behaviour); describing-function methods for analysis of nonlinear systems
- Taught ME for 3 years (systems and controls), Oklahoma State University, Stillwater; more describing-function method research
- GE Corporate R&D → nonlinear control, expert systems for real-time control, computer-aided control engineering; industrial R&D in (for example!) modelling and simulation of chemical processes, robotics, aircraft engine controls, aerospace systems, ...
- NSERC Industrial Research Chair, UNB 1994-2001 → R&D in self-optimizing systems, modelling & simulation, nonlinear controls (see my web page for further details)

My goal at UNB: produce research and students that Canadian companies will employ

Career Interests

History:

- Degrees in Electrical Engineering & Applied Mathematics . . .
- but it's all been about applications, really:
  - Missile Guidance & Control
  - Aerodynamics & Flight Control
  - Mechanical / Electro-mechanical Systems
  - Process Systems (silicones production)
  - Aircraft Engines
  - Oil & gas processing processes
  - Semiconductor processing
  - Simulating systems with discontinuities

Approach:

- Developed strength in modelling & simulation
- Learned a lot about analysis and design software ("Computer-Aided Control Engineering" – CACE)
- Learned how to take theory and turn it into practical tools
- Developed an open mind and enthusiasm for new areas

Some Lessons Learned

- Systems problems in industry are usually **multidisciplinary** and require **team effort**
- **Understanding "the physics"** is more important than a lot of theory
- **Ingenuity and "feel"** are at least as important as theory
- **Common sense** is critical – but it takes time & effort to develop
- The **broader your perspective** the better
- A **strong background in systems & control** prepares you for a **wide variety of career paths**

My objective is to prepare you for a good position in the real world to the extent possible . . .

Lessons Learned (Cont'd) – Teaching

What employers say: "We want our young engineers to know ladder logic and assembly language for the Motorola 68000." (well, that was a few years ago ...) or "How to assemble a control system with off-the-shelf components and tune it"

What engineers say: "We want help with the basics –

- Modelling & simulation
- Frequency-domain analysis and design methods
- Dealing with nonlinearity and other nasty problems
- How you can help:
  - work with us on projects
  - find/buy/develop CACE software
  - provide tutorial guides and workshops

We can get all that other stuff from product spec sheets and manuals."

This has had a **major effect** on what I teach – I focus on what **engineers need/want**, not what employers say.

- Few companies are looking for theoretical control engineers
- **Virtually every industry needs broad-based, practical systems engineers (industrial control engineers)**

Why is Control Important?

- Feedback and control systems are **everywhere** – in your appliances, automobiles, digital cameras, in factories (from numerically- controlled machine tools to french fry production), in organizations, in biological and environmental systems, in your own body ...

- Life without automatic control would be **very difficult** (imagine having to regulate the temperature in your home manually ... "Sam, put more coal in the furnace")

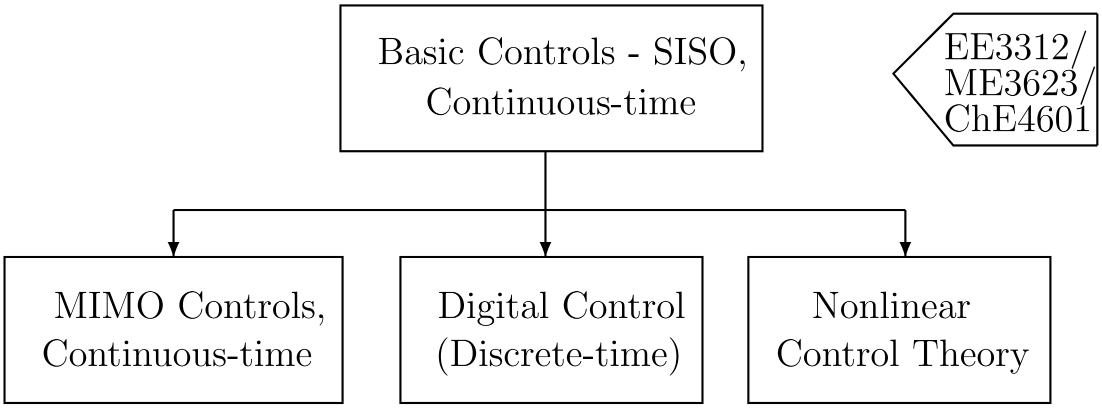
- Many systems / processes **perform much better** with control (e.g., gas mileage and emissions of your automobile, stability control, climate control)

- Many tasks **cannot be done** without feedback (there are aircraft that cannot be flown without flight controls; also, imagine driving your car without visual feedback)

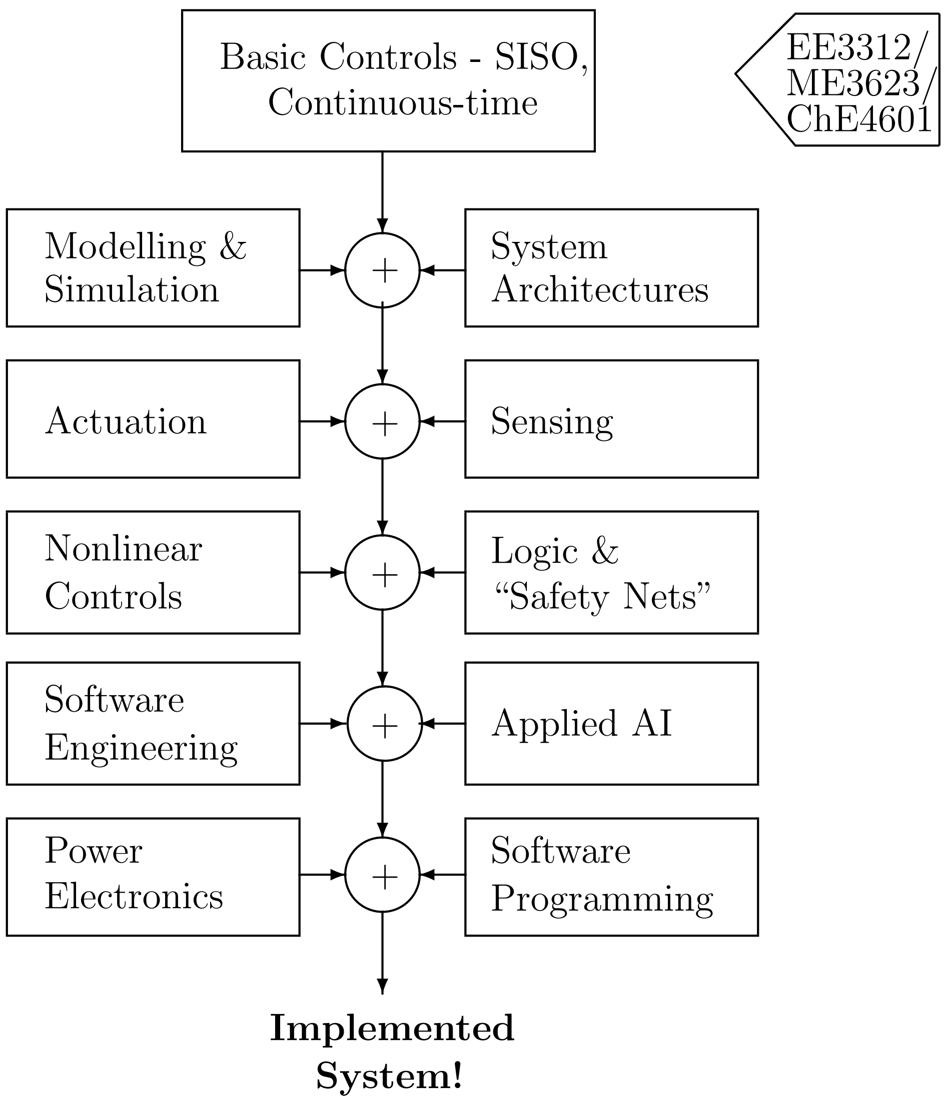
- In industrial terms, control is a major contributor to:
  - **producing a quality product at a competitive price** (controls in the plant)
  - **producing a product with more or enhanced functionality** (controls in the product)

What Is "Industrial Controls"?

NOT a Narrow/Theoretical Topic . . .



. . . but a **Broad/General One:**



Industrial *vs* Theoretical Controls

- **Control Theoretic Perspective (found in too many textbooks):**
  - "Give us a plant model and we will solve your control problem."
  - "Sensing and actuation are 'givens'."
  - "The most desirable solution is an advanced (e.g., H^∞) controller that *(for a linear model)* gives the utmost in performance in the face of well-defined models of uncertainty and/or failure."

  These attitudes tend to give academic controls a "bad name" in industry.

- **Industrial Control Perspective (most companies):**
  - "Make it work!"
  - "Make it simple!"
  - "Make it cheap!"
  - "Make it reliable!"

  Control **theory** usually addresses only 10% of these problems.

- Another important issue: a system (over) engineered to be linear is rarely practical

Industrial Perspective (Cont'd)

Example of "(over) engineering a system to be linear" (from robotics):

1. **Elegant design**: large, stiff links (no flexibility), large precision servo motors (no saturation), harmonic drives (no backlash), precision bearings (no stiction) – cost \$ 650,000, weight-to-payload ratio 50:1, accuracy 200 μ, ...

2. **Practical design**: light (flexible) links, smaller cruder motors and bearings, etc. - with a nonlinear controller that compensates for nonlinearity and flexibility as best it can – cost \$ 90,000, weight-to-payload ratio 25:1, accuracy 1000 μ, ...

Design 1 may make sense if you **really need** high precision (building a Mars rover) – but Design 2 will be much more cost-effective if you can use your ingenuity to "get away with it".

Second *really bad* example of "over-engineering a system to be linear": Linear *vs* relay control of temperature in a tropical fish tank – the former is based on control theory, the latter on more basic analysia,s or modelling and simulation, or even "tinkering".

Outline / Guided Tour

- **Introduction / "The Big Picture"**
- **Preliminaries / Basic Properties of Systems:** Modelling and model types, a **brief** review of modelling electrical, mechanical and electro-mechanical systems; equilibria and equilibrium finding, small-signal linearization, role of simplifying assumptions – inclusion (and exclusion!) of nonlinear effects; deciding appropriate dynamic order; "truth" and "design" models
- **Modelling and Simulation:** Model types and simulation methods; modelling and simulation in MATLAB
- **Actuation:** Examples of basic electro-mechanical and (electro-)hydraulic actuators; modelling considerations
- **Sensing:** Examples of some rudimentary sensors; modelling considerations; accuracy, dynamic range, linearity, static and dynamic response, loading;
- **Model Identification:** Method of least squares; application to fitting static nonlinearities; application to identification of linear dynamic models; limitations; a glimpse of more advanced methods

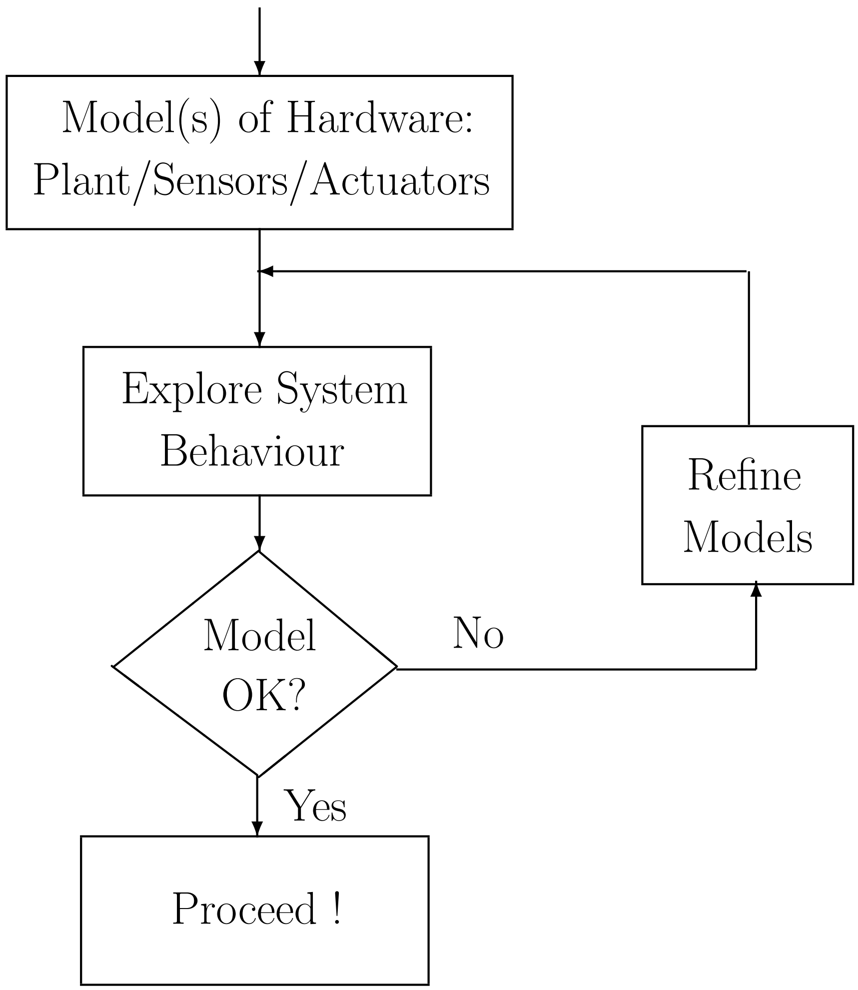
Outline / Guided Tour (Cont'd)

- **Basic Controls Concepts:** An overview of open- and closed-loop specifications in the time, frequency and s-plane domains
- **Linear Controls:** frequency-domain methods, root locus design, controller tuning rules
- **Dealing with Nonlinearity:** Stability definitions, theorems and applications; absolute stability criteria (rigorous yet easy to apply!); sinusoidal-input describing function methods (analysis of oscillations and forced periodic response, making control systems "robust")
- **Applied Artificial Intelligence:** Creating systems that are "more autonomous" and "smarter"; rule-based systems, fuzzy logic, neural nets (maybe)

Note: The exact coverage may be adjusted as we proceed.

What's Involved

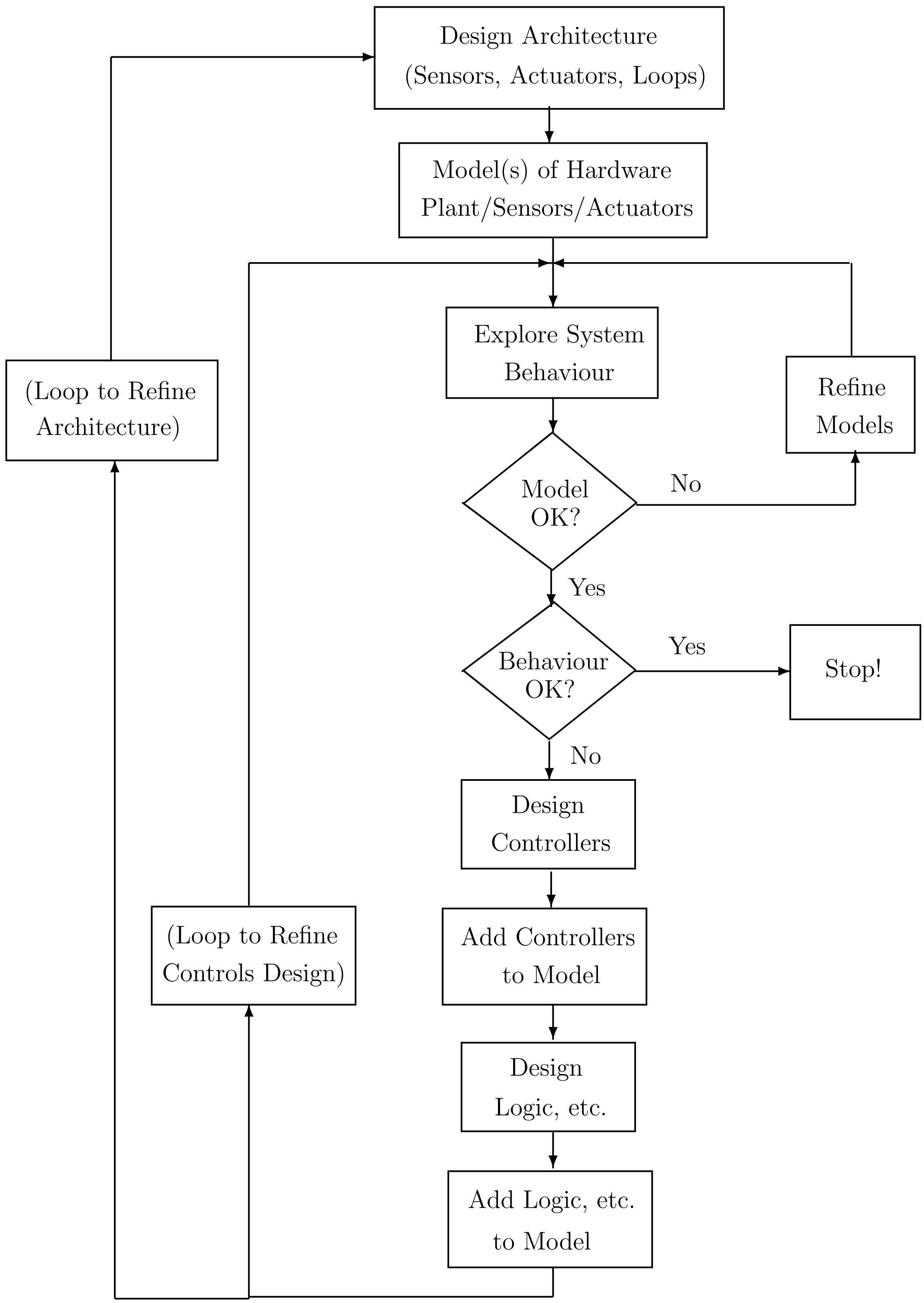
Industrial controls engineering is **highly iterative**:



This is usually the **hard part!**

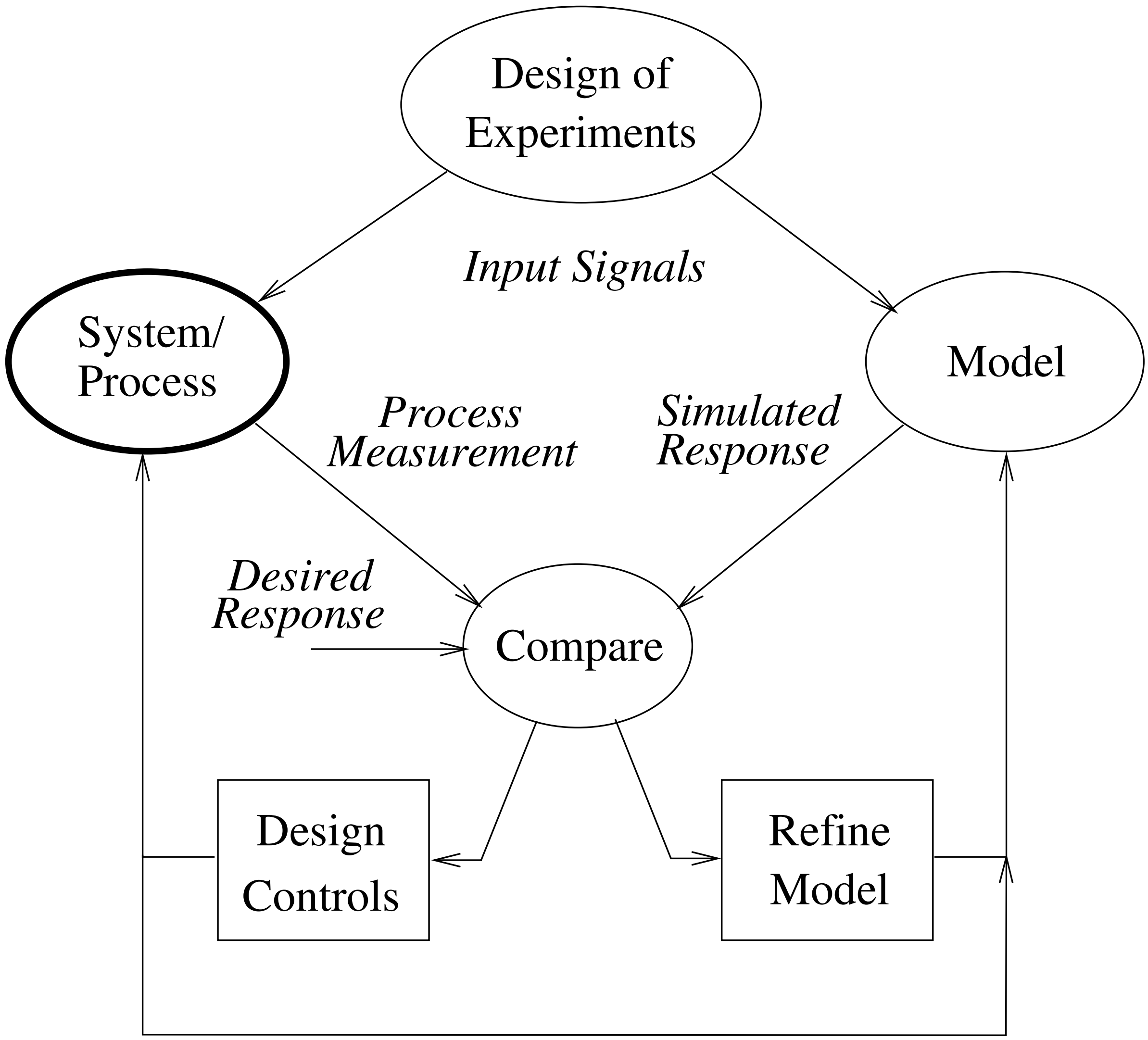
What's Involved (Cont'd)

Did I mention that controls engineering is **highly iterative?!**



What's Involved (Cont'd)

Another view of the Systems Engineering Process (Nachtigal):



Note: Systems & Control may not be as "neat" as a flowchart . . .

“Envelope” of Model Validity

Example: iterative servo motor modelling

- **First cut**: $|I_f| < 4$ A, $|I_a| < 4$ A $\Rightarrow$ take parameters from the spec sheet, adjust until the step response agrees well with lab tests.

- **Design a preliminary control system**: reveals that more torque is required $\Rightarrow$ two options:

  - Specify a bigger motor $\Rightarrow$ weight and cost increase, **or**

  - Drive the motor harder $\Rightarrow$ need a more realistic motor model:

    * Add saturation nonlinearities

    * Add a thermal model

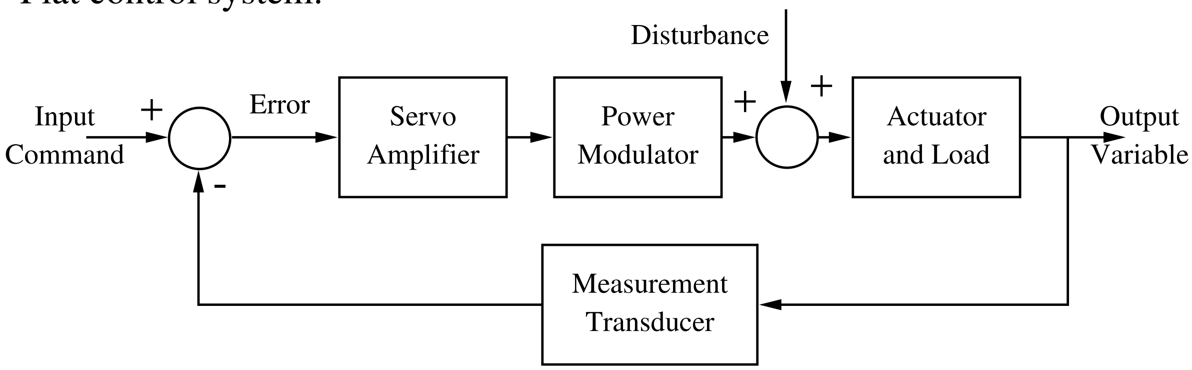
- **Refine control system design**: discover more bandwidth is needed for good control system performance $\Rightarrow$ add inductor lags to motor model

More on this topic later . . .

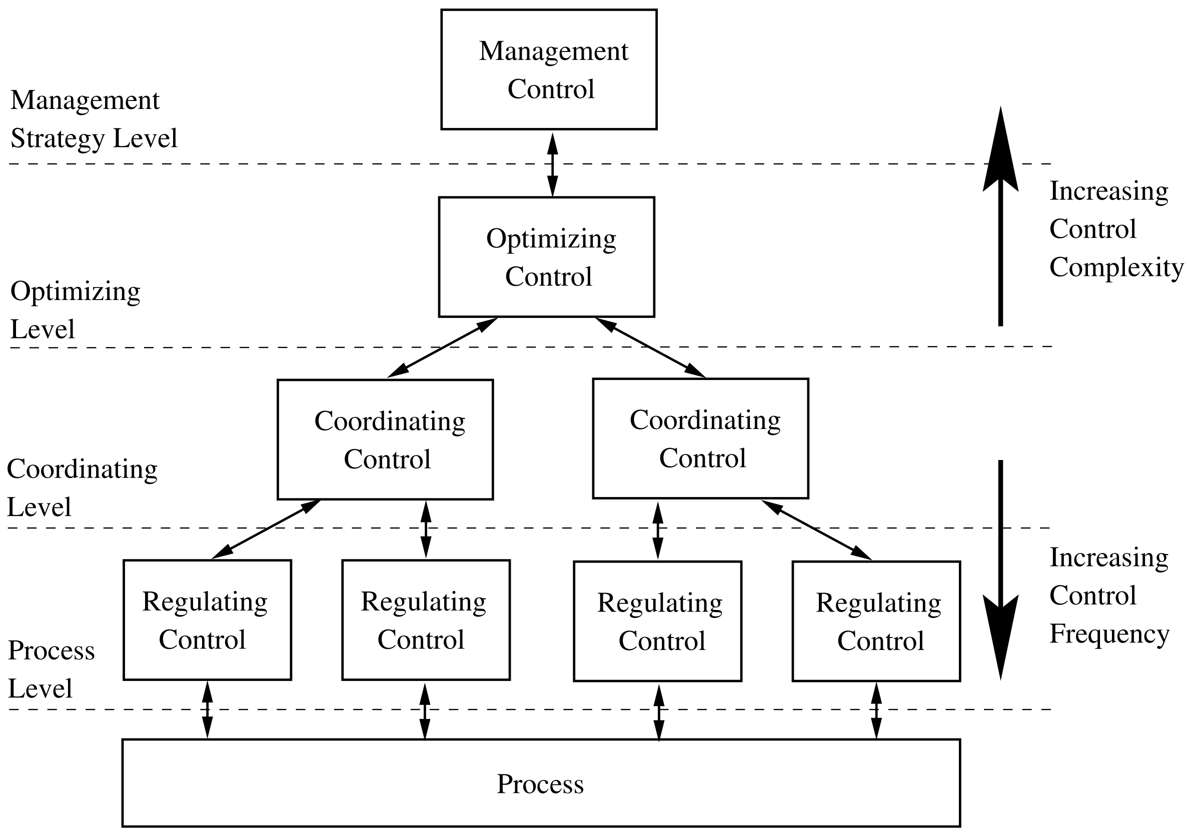
What's Involved (Cont'd)

Industrial control systems may be "flat" or hierarchical:

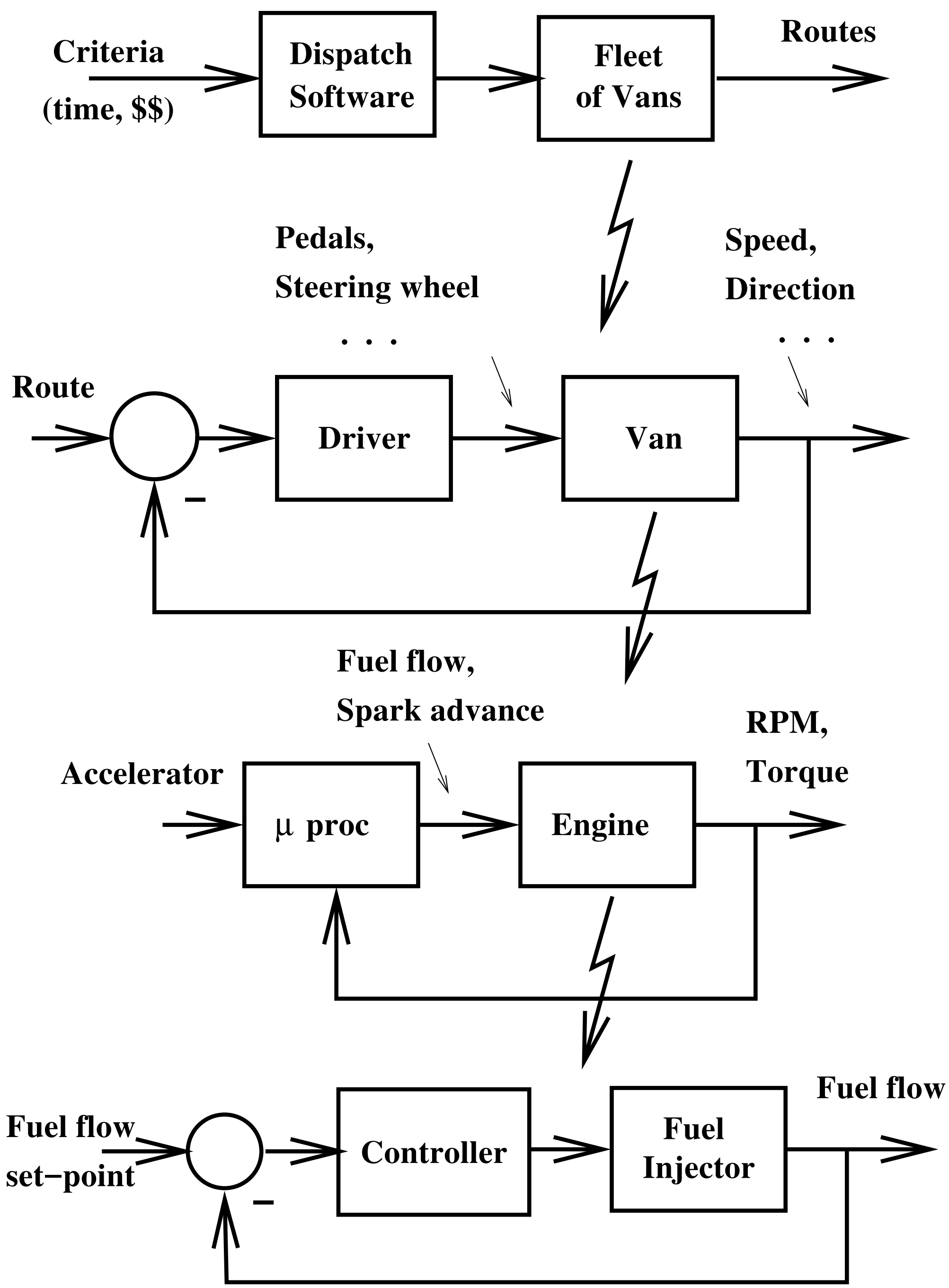
- Flat control system:



- Multi-level control system:



Example of Multi-level Controls



Imagine how complicated this is for **autonomous vehicles** – you have to replace the driver with algorithms and controls, adding at least another layer to the system

Summary

- Control engineering is a profession with a broad spectrum of interesting applications
- A successful control system design requires a good understanding of the "plant" – obtained by experience with that plant or by development of a good model
- A successful control engineer has to work with other contributers
  - Someone with expert knowledge of the plant
  - A software engineer
  - Who else?
- A successful control system design is critical for final project success – if the control system does not achieve good performance your product will not be accepted