

# CONCEPTS OF DESIGN

**MIT Subjects 2.017 & 2.019**  
**Design of Systems for Random Environments**  
**Design of Ocean Systems**

*CHALLENGE STATEMENT FOR 2006*

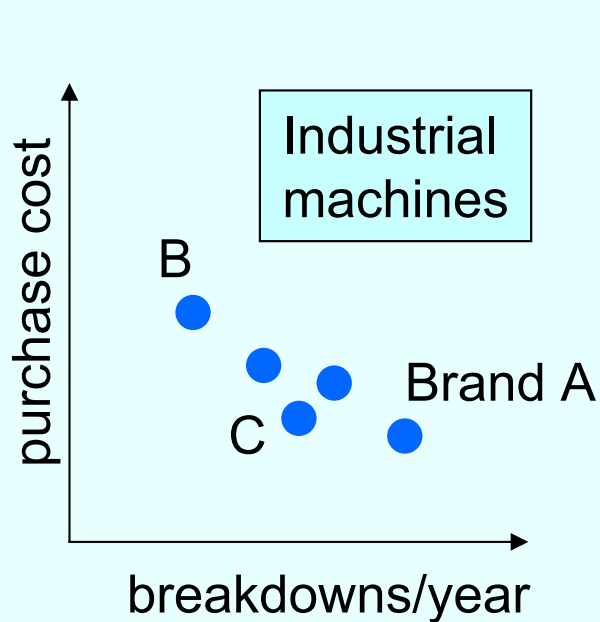
Your goal is to create a new capability in ocean observation, by ***constructing a small, autonomous surface vessel system capable of tracking a subsurface acoustic source.*** In the first part of the subject (2.017), you will perform modeling tasks to support informed decisions, conduct experiments, test hardware, and build working subsystems. In the second part of the course (2.019), you will complete integration, perform field tests, and quantify the performance of the system.

**PROJECT TECHNICAL GOALS (descending priority)**

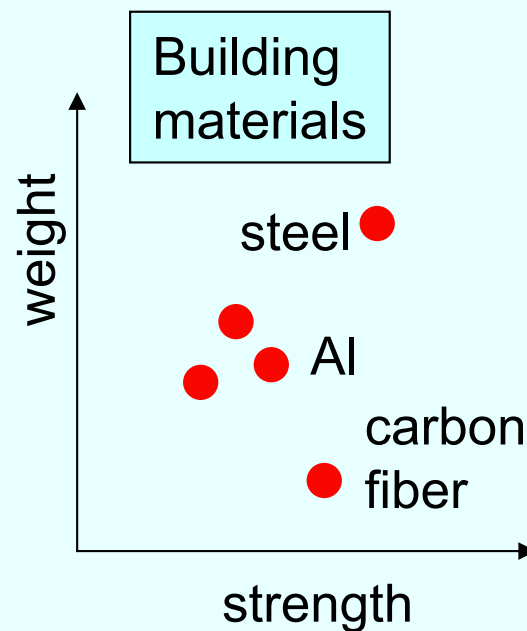
- Demonstrate a small, autonomous surface vessel homing to a subsurface acoustic beacon.
- Demonstrate this in Sea State 3 conditions.
- Demonstrate navigation in a global frame, e.g., GPS, compass.
- Demonstrate waypoint autopilot capability.

# Tradeoffs

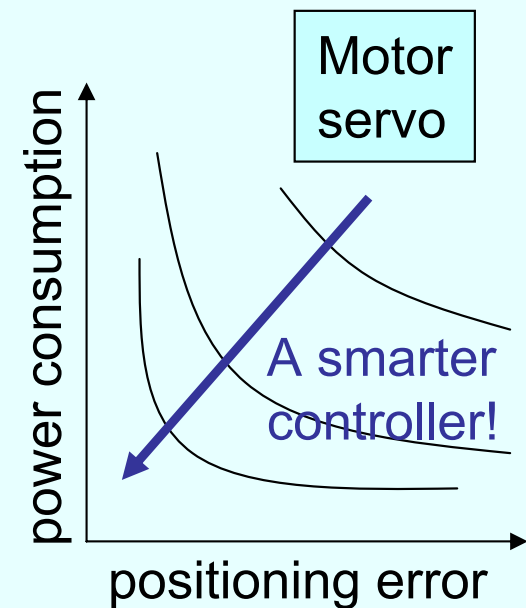
- Everything interesting that you do in LIFE and in design is a tradeoff – *getting what you want at the expense of something else.*



*Old vs. used?  
Maintenance?*



*Cost? Fatigue?  
Heterogeneous?  
Finish? Corrosion?*

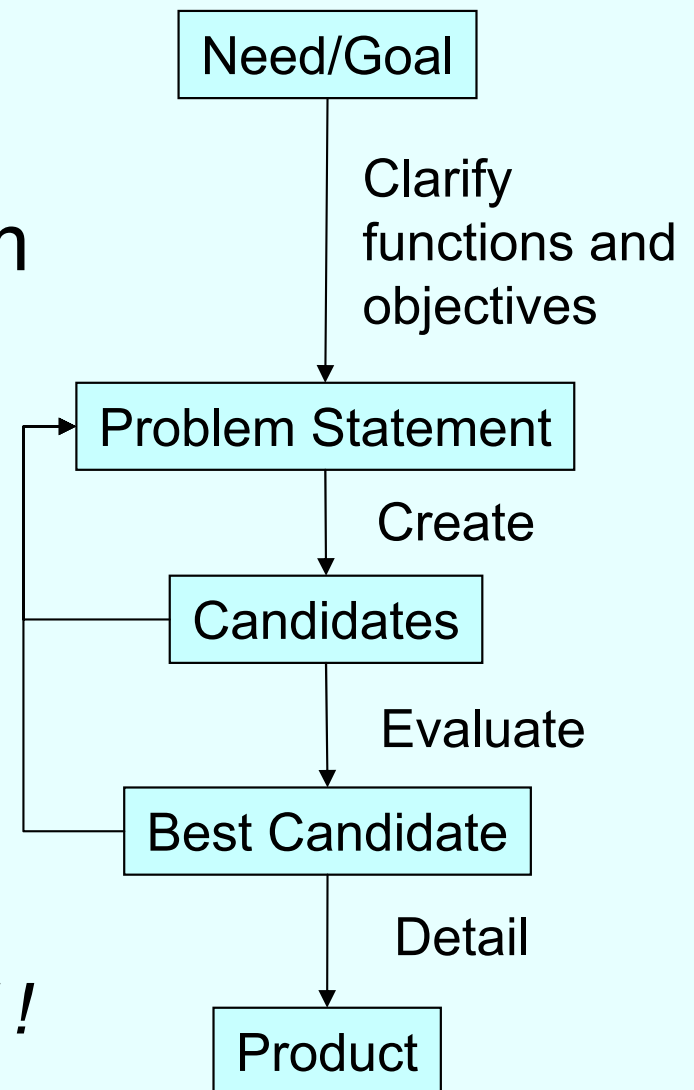


*Complexity?  
Robustness? Cost?*

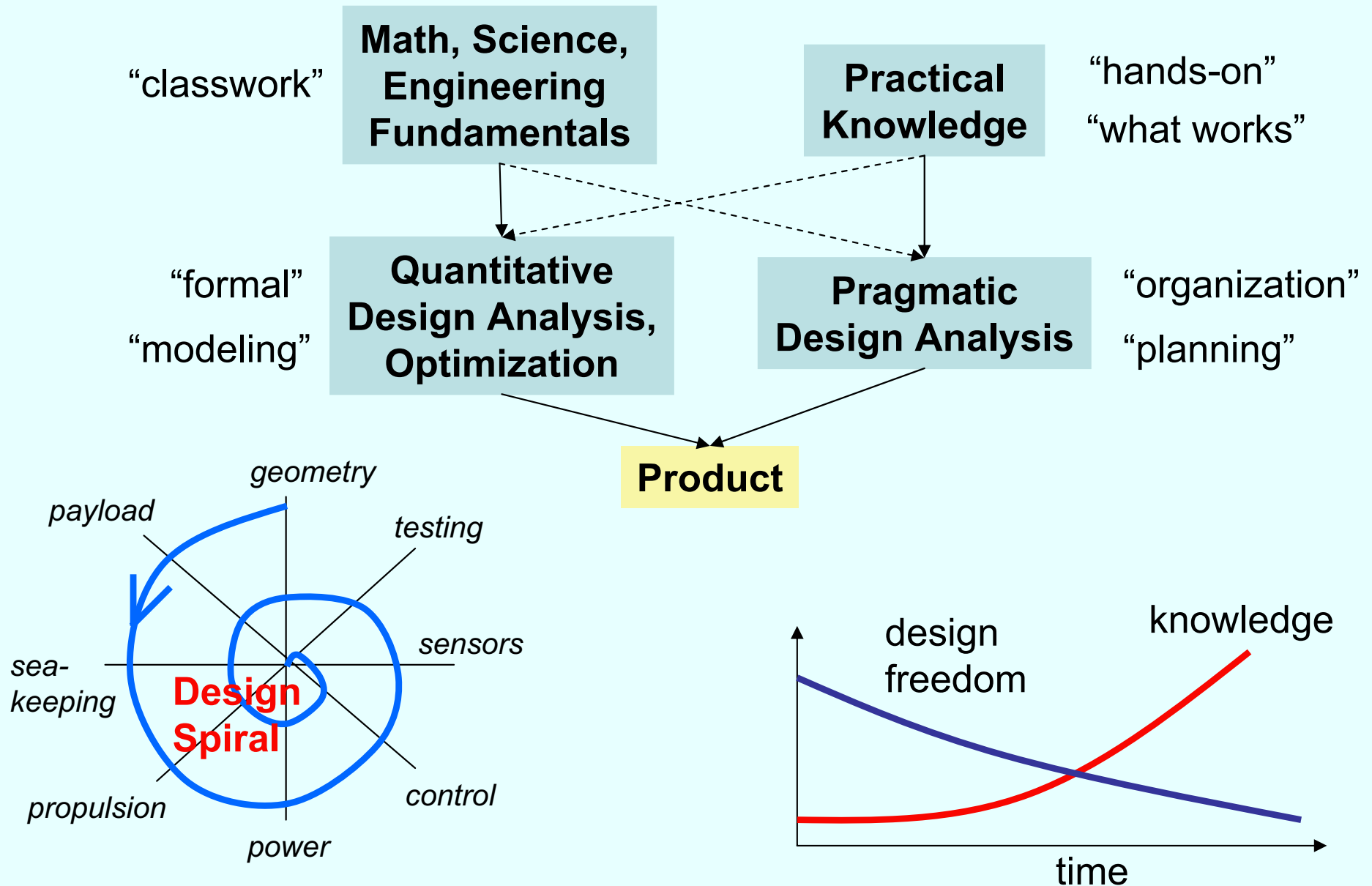
# Fundamentals of Design

- A process of
  - Understanding the problem
  - Creating solutions
  - Evaluating solutions
  - Making revisions and refinements
  - Detailed design

***DOCUMENTATION THROUGHOUT !***



# Other Views of Design ...



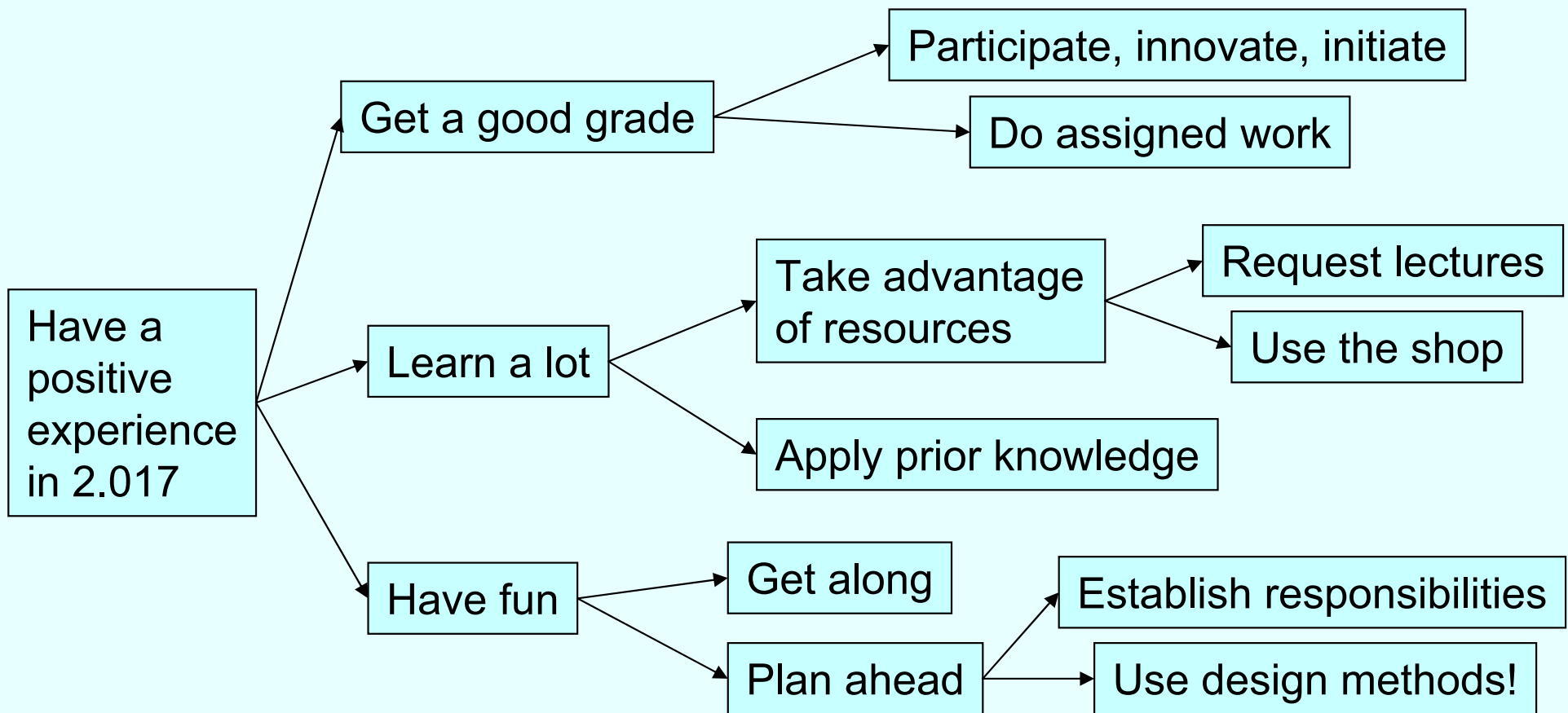
# The Objectives Tree

Broad objectives...

→ HOW? →

← WHY? ←

... specific objectives



# A Decision Matrix: Flettner Rotorship

What is the impact of these ENGINEERING ATTRIBUTES, relative to REQUIREMENTS?

A: High rotary speed

B: Large rotor diameter

C: Stiff inner structure

D: Number of rotors

E: Height of rotor

REQUIREMENTS	Weight	A	B	C	D	E
Propels the boat	40	2	2	0	2	2
Robust to damage	10	-1	0	2	-1	-1
Easy to fabricate	30	-1	0	-1	-1	-1
High boat stability	20	0	-1	-1	0	-2
Weighted sums:		<b>40</b>	<b>60</b>	<b>-30</b>	<b>40</b>	<b>-40</b>

- Attribute B (a large rotor diameter) is **most important** to meeting the requirements.
- Attributes C and E (stiff inner structure, tall rotors) have **negative** impact on meeting the requirements.
- The calculation helps identify and document priorities and the direction of the design.
- It suggests areas where further clarification of requirements or attributes is needed.
- Related to “House of Quality” and “Quality Function Deployment”

# Knowledge vs. Confidence

- Knowledge about an idea and confidence in it are not the same thing!
- *Target*: a specification, criterion, requirement
- *Idea*: one possible solution
- A measure of knowledge: what is the probability of you getting a true/false question right about the idea?

*Clueless:  $K = 0.5$*

*Expert:  $K = 1.0$*

- A measure of confidence: what is the your certainty that the idea will meet the target?

*Impossible → Doubtful → Likely → Perfect*

*$C = 0.0$*

*$C = 0.3$*

*$C = 0.7$*

*$C = 1.0$*

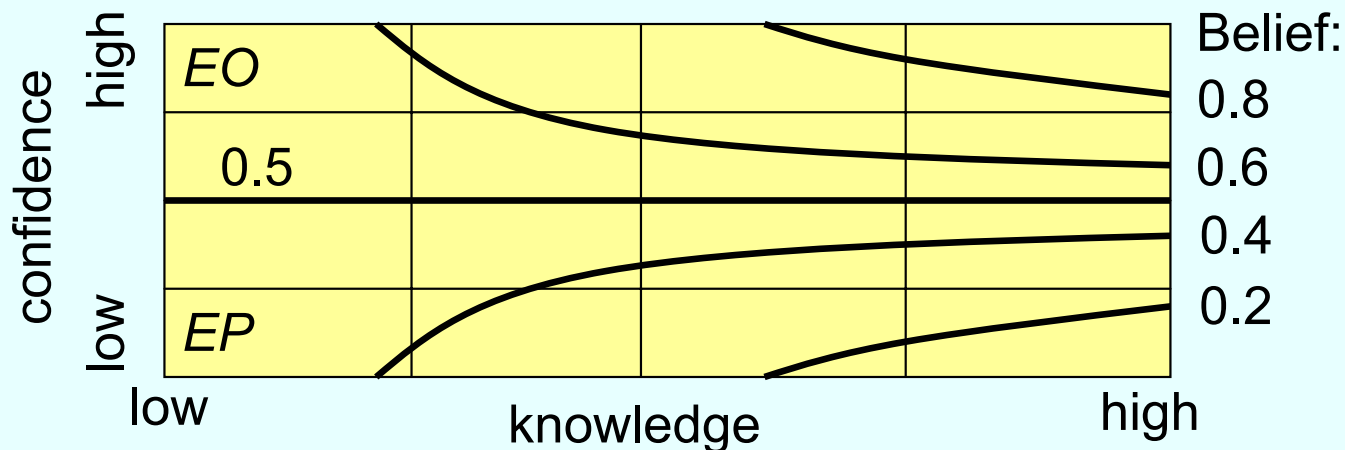
Confidence is subjective!

# Combine Knowledge and Confidence: Belief

- A measure of belief: confidence that an idea meets the target, based on current knowledge.
- *Using the above numerical values and Bayesian analysis, Ullman (2001) computes*

$$\mathbf{Belief = 2KC - K - C + 1,}$$

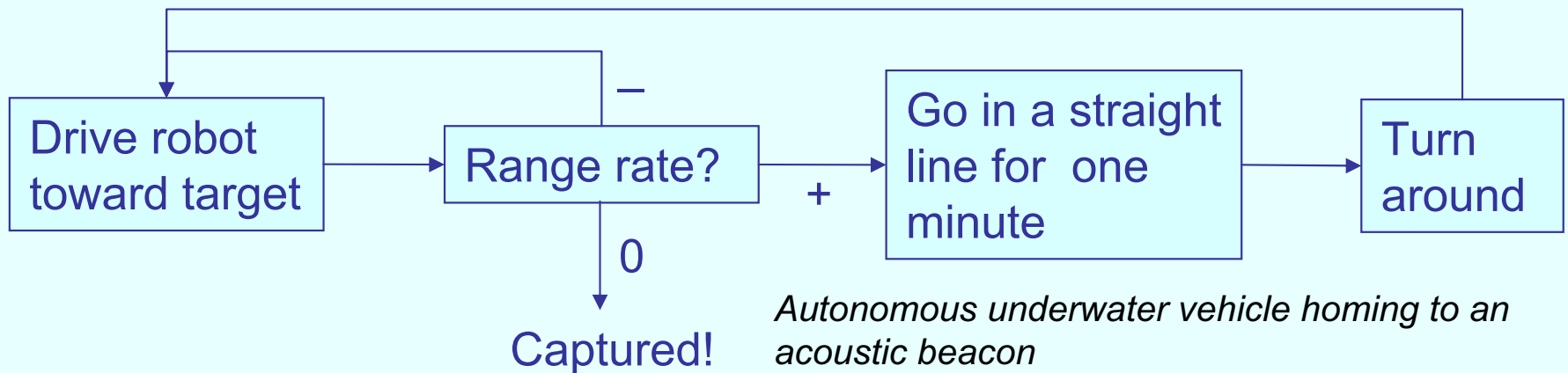
*leading to a “belief map” →*



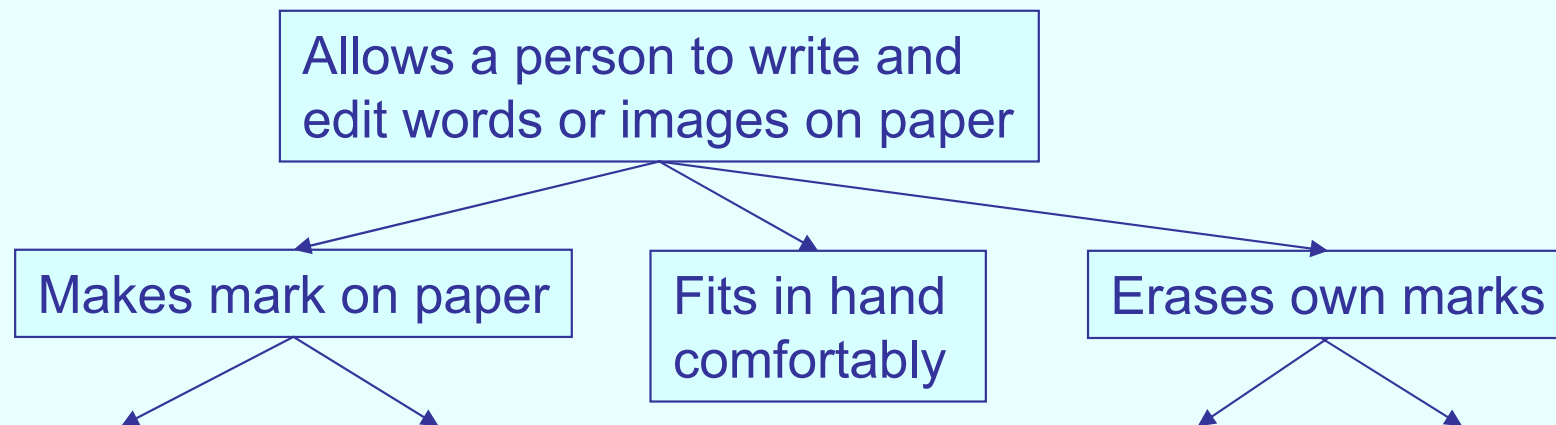
Decisions should be based on a high level of belief – you have to have knowledge of the idea AND confidence that it meets the target

# Function Analysis

**Flow-Chart:** Algorithm design, Processes

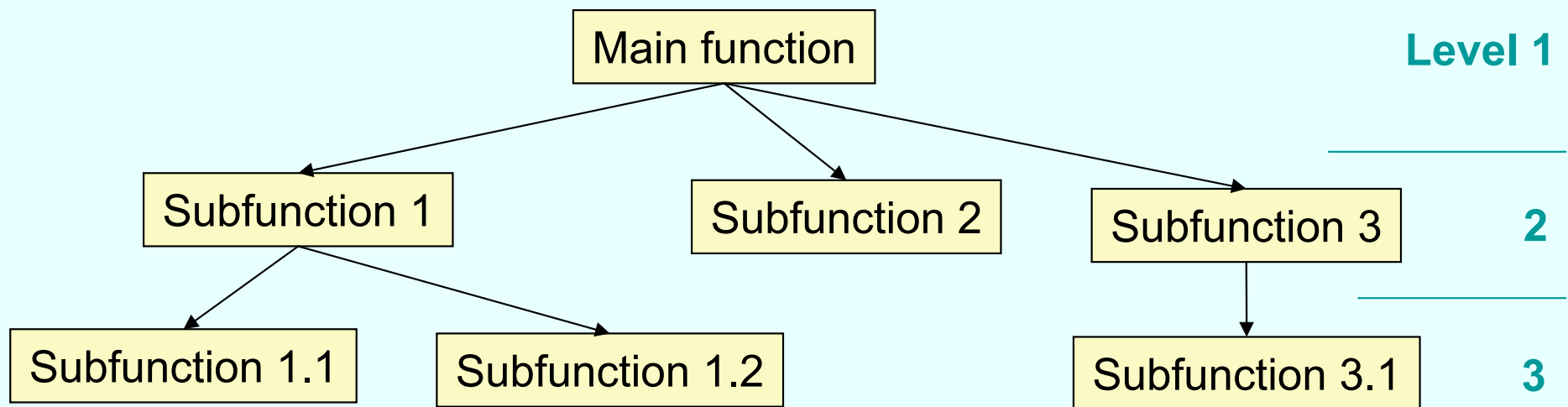


**Layered Functions:** A complex system having multiple functions



# Understanding Complexity

- Complexity is often what causes the hardest problems – and solutions that are time-consuming and expensive.
- High costs of errors once a product is out the door.
- Piecemeal vs. Holistic design.
- Fundamental rules of design – e.g. grounding & isolation, stainless steel, well-known vendors, etc.
- Basic rule: Layered Sub-functions → Complexity.



# Why does it take so long!?

Person-hours design effort can be estimated as

$$H = A * B * C \text{ where}$$

**A** = a constant depending on communication and size of engineering group: values typically in the range 30-150 in commercial world – it may be lower or higher for students!

**B** = sum of products of level number and number of subfunctions at that level (1+6+9 = 16 in figure).

**C** = difficulty (1 is easy – known technologies, 3 is hard – many unknown technologies)

→ *Even a seemingly simple project easily runs into hundreds of hours*

→ *Role of complexity should be kept in mind when milestones are defined and set*

# Gantt Charts: a Graphical Schedule

## Documentation

Clarify problem

Modelling

Brainstorming

First design iteration

Experiments & research

Test candidate solutions

Second design iteration

Finalize design choices

Order parts

Make machine drawings

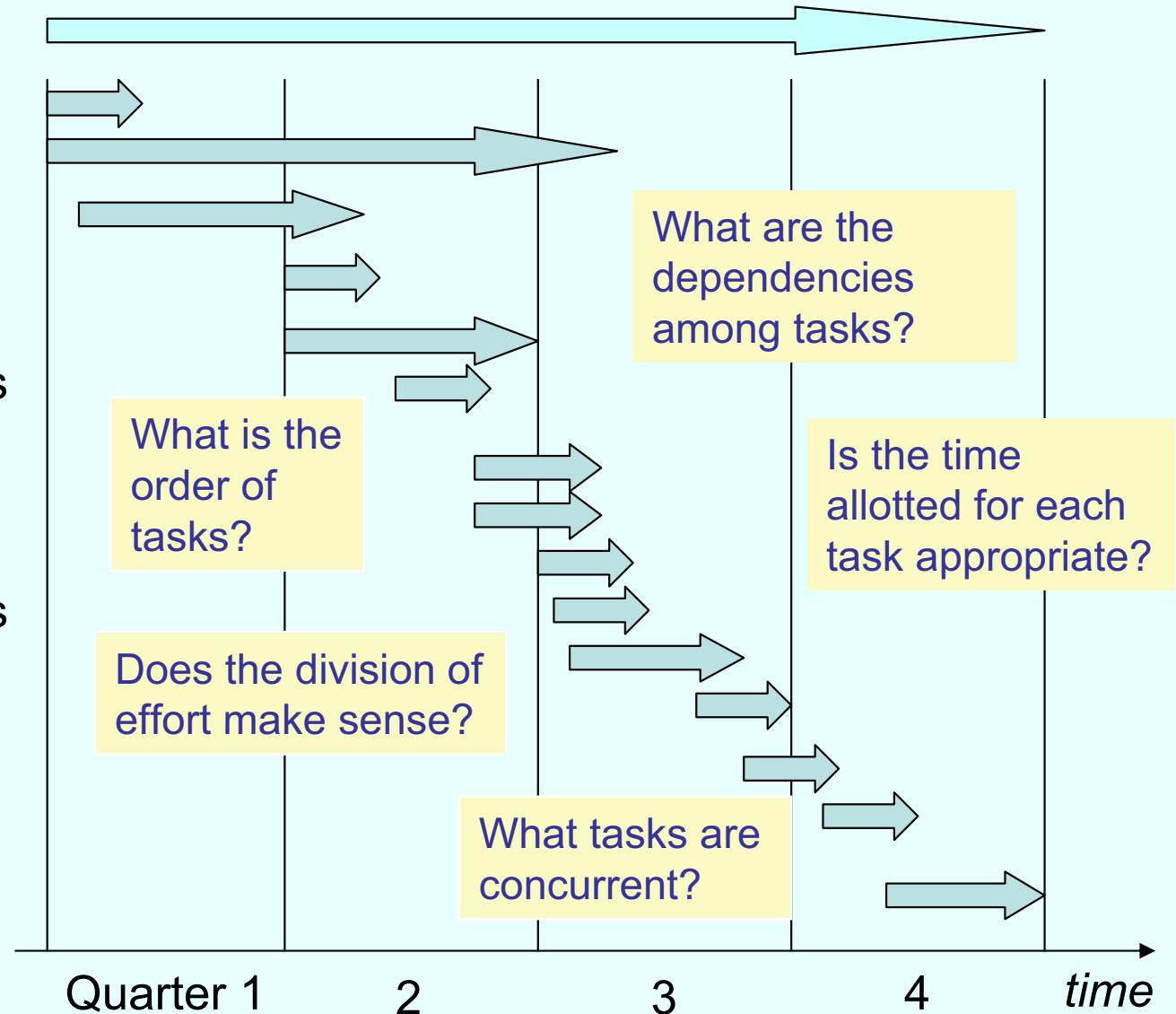
Fabricate subsystems

Assemble system

Integrated testing

Field tests

Documentation



# References

- D.G. Ullman. The mechanical design process (Third edition). New York: McGraw-Hill. 2003.
- N. Cross. Engineering Design Methods: Strategies for product design (Third edition). New York: Wiley. 2000.