Introduction to System Architecture

Architecture to Value

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January 5, 2007

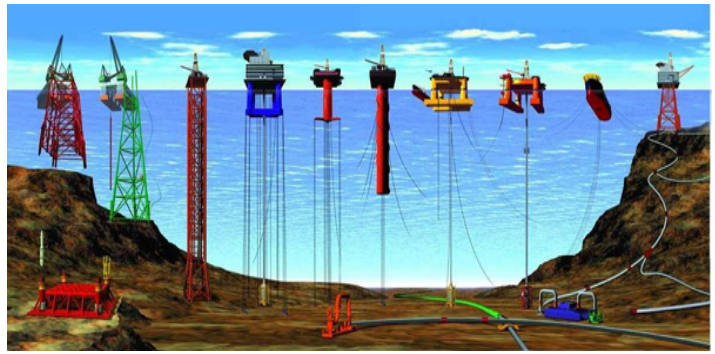
Rev 2.0

Today's Topics

- Objectives, Expectations and Administration
- Key Ideas
  - Architecture
  - Architecting
  - the Product Development Process (PDP)
- Form of Systems
- Intro to Upstream Processes
  - Technology infusion

The Opportunity

- **We conceive, design, implement and operate complex and sometimes unprecedented systems**
- **Do they meet stakeholder needs?**
- **Do they integrate easily, evolve flexibly, operate simply and reliably?**
- **Well architected systems do!**
  - **Link benefit to cost**
  - **High leverage as early design process**
  - **Source of competitive advantage**



Source: NOAA

Source: NASA

Overall Learning Objectives

Students will be able to:

Apply the principles, processes and tools of system architecture to:

- Structure and lead the early, conceptual phases of the product development process

- Support the process through development, deployment, operation and evolution

Learning Objectives

- **Discuss systems, systems thinking, products (value and competitive advantage), the PDP and the "role" of architecting in the PDP.**

- **Analyze and critique the architecture of existing systems, create the architecture of new or improved systems, and produce the deliverables of the architect.**

Learning Objectives

- **Drive the ambiguity from the upstream process by defining the context and boundaries of the system, interpreting needs, setting goals and defining the externally delivered functions.**
- **Create the concept for the system, consisting of internal function and form, while thinking "holistically and out of the box" when necessary.**
- **Manage the evolution of complexity in the system so that goals are met and function is delivered, while the system is comprehendible to all during its design, implementation, operation and evolution.**

Learning Objectives

- **Challenge and critically evaluate current modes of architecting, and create new synthesized modes.**
- **Develop for themselves the guiding principles for successful architecting.**

To prepare students for their first, second, and third jobs after SDM.

This is a course in how to think, not what to think

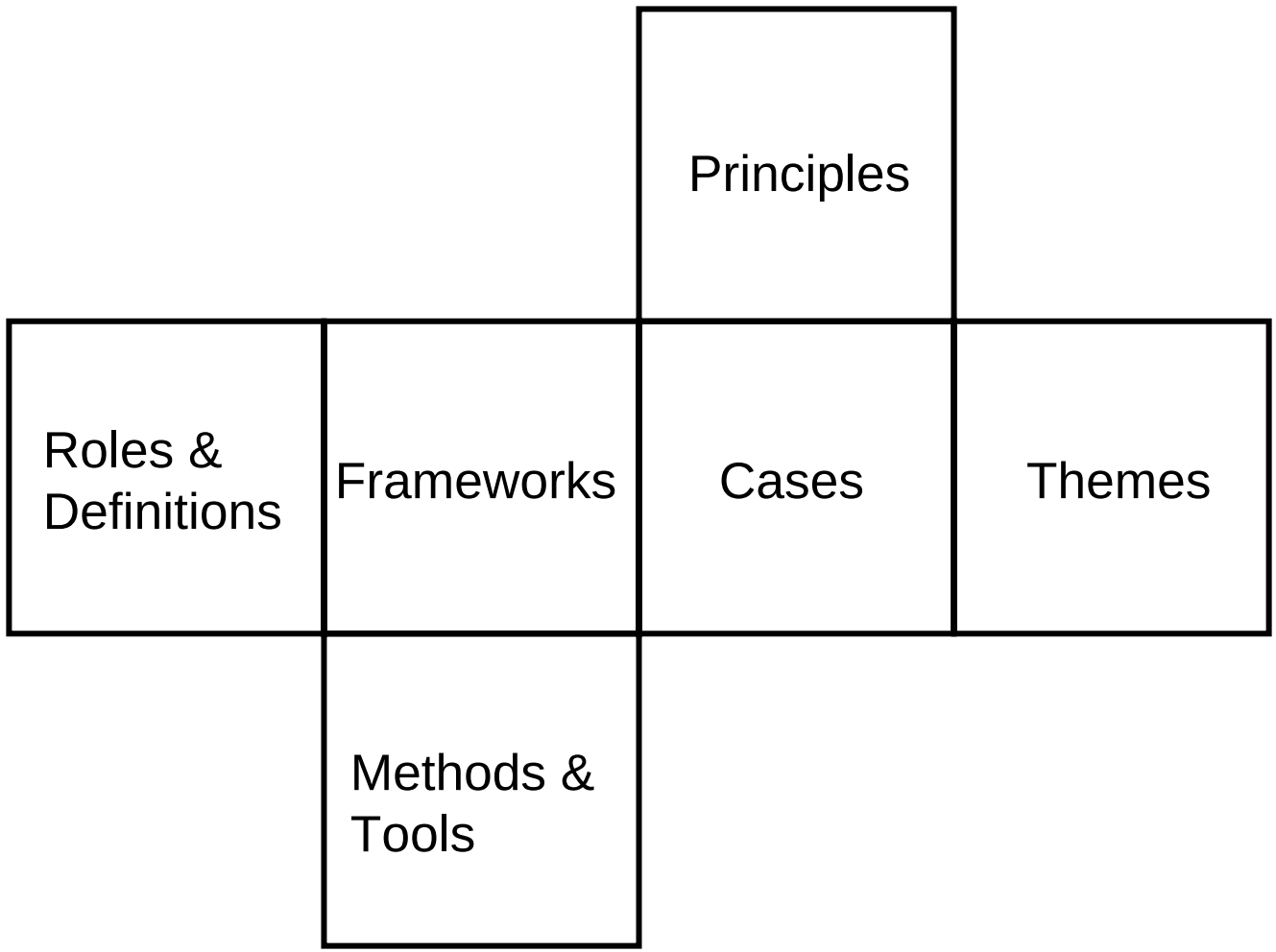
Implicit Subject Objectives

- **To be synthetic**
  - **Scale up existing knowledge**
  - **Tie together SDM Curriculum**
- **To encourage a *global* view**
- **To learn from best practice in architecture (search)**
- **To learn from new thought in architecture (re-search)**
- **To leave you with a set of personalized tools for architecting**

Expectations

- **Act professionally**
- **Think creatively**
- **Work in a scholarly manner**
- **Speak and write clearly and concisely**
- **Respond punctually**
- **Whine little**
- **Have fun**

Architecture - Pedagogy



Master Schedule

Jan: "Architecture 400"

- **Vocabulary**
- **Architecture**
- **Analysis of architecture - what is architecture?**

Sept - Nov: "Architecture 401"

- **Upstream processes (leading to the product case)**
- **Downstream processes**
- **Cases and critique or architecture**
- **Synthesis of Architecture - how to make good architecture**

Dec: "Architecture 537"

- **Advanced (but important) topics**
  - **Supply chains**
  - **Platforms and product families**
  - **Reuse of legacy elements**

Schedule, etc.

- IAP vs. Second “Half”
- Detailed IAP schedule
- Syllabus Package
- Opportunity Sets
  - 1, 2, 3, 4 in assigned groups
  - 5 (Technology Search) in organic groups of like interest (3±1)
- Texts
- Grading
- Dissemination
- Academic Integrity

¿What is Architecture?

- **What do you think?**

Architecture

- **The structure, arrangements or configuration of system elements and their internal relationships necessary to satisfy constraints and requirements. (Frey)**
- **The arrangement of the functional elements into physical blocks. (Ulrich & Eppinger)**
- **An abstract description of the entities of a system and the relationship between those entities (Crawley et al.)**
- **The embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of interfaces among the elements and with the surrounding context. (Crawley)**

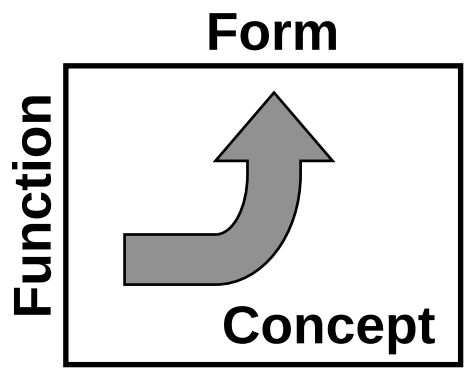
Definitions - Analysis and Synthesis

- **What do the definitions have in common?**
- **What distinguishes them? What is the underlying cause for this distinction?**
- **Synthesize a definition that works for you, in your job context.**

Consensus Definition: Architecture[1]

- **The embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of interfaces among the elements and with the surrounding context. (Crawley)**

- **Consists of:**
  - **Function**
  - **Related by Concept**
  - **To Form**



1 - when I introduce a term and define it, I will underline on the chart and include it in the glossary

Concept?
Function?
Form?
Interfaces?
Context?

Architecture – Civil

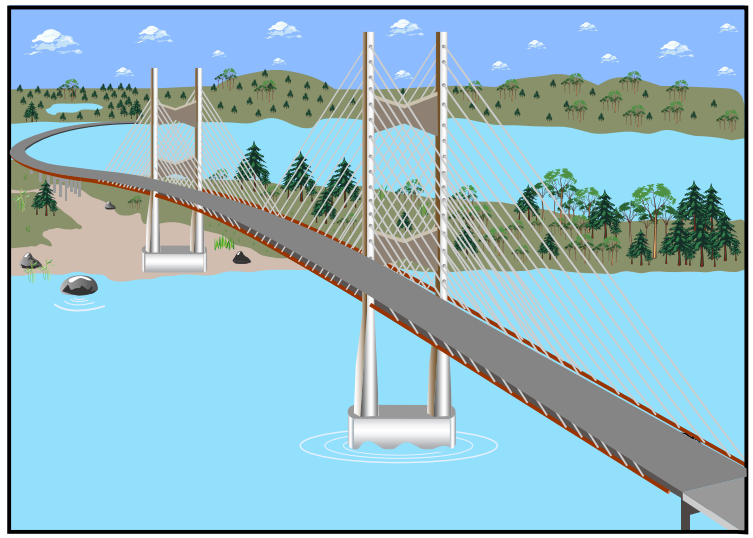
Several diagrams removed due to copyright restrictions.
Comparing plans for beach house and “Florida” house, from http://www.coolhouseplans.com

Source - www.coolhouseplans.com

Concept?
Function?
Form?
Interfaces?
Context?

Architecture – Mechanical

Figure by MIT OCW.



Cable-stayed bridge

Courtesy of Rich Niewiroski Jr.
(http://www.projectrich.com/gallery)

Suspension Bridge

Concept?
Function?
Form?
Interfaces?
Context?

Architecture - Communications Network

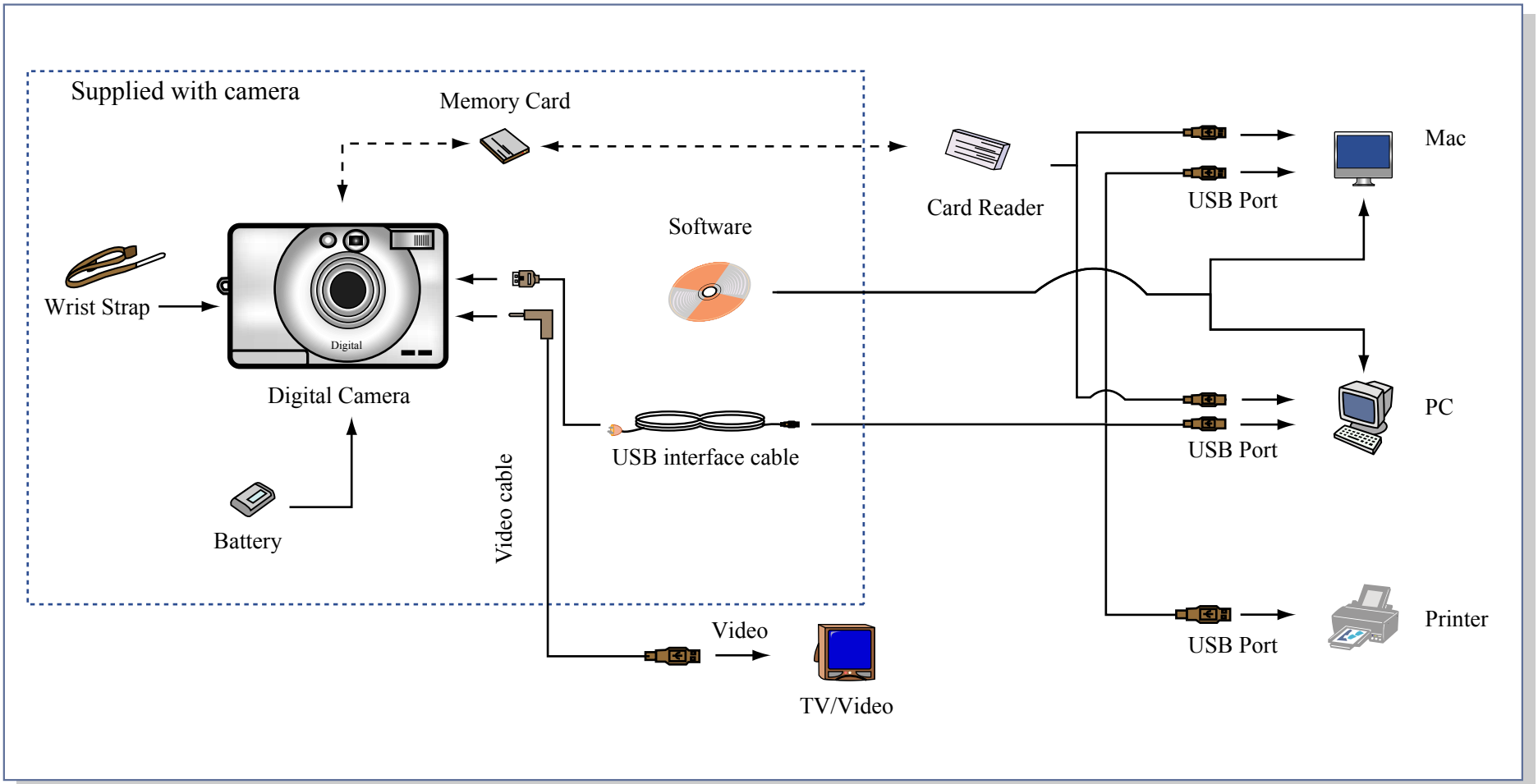


Figure by MIT OCW.

Concept?
Function?
Form?
Interfaces?
Context?

Architectural - Instructional

Courtesy of ENPHO. Used with permission.

Architecture - Thought Assignment

- **What is the architecture of common things? What is the concept, function, form, interfaces and context?**
- **What is the architect trying to achieve?**
- **What makes an architecture "good"?**

Try to internalize what constitutes "an architecture."
This will appear on OS 2 and 4.

Architecting

- **An architect works by applying:**
  - **Relevant modes of thought, including creative and *critical thinking***
  - **The approaches of architecting, including *holism*, focus, etc.**
  - **The *principles*, *processes* and tools of architecting**
  - **And a lot of wisdom and experience!**

Suggested Process for Critical Thinking

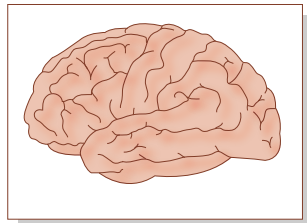


Figure by MIT OCW.

- Opportunity, challenge, or reference example identified in context
- Thinker develops an approach option
- Thinker surveys other approach options, then compares the "surveyed" options with each other and the "developed" approach option
- Thinker synthesizes a context-appropriate "best" option

Example: Critical Thinking

- **We just did this when talking about architecture:**
  - **We identified the opportunity when I asked you for your definition of architecture**
  - **You developed your own definition**
  - **We listed several others and compared them**
  - **I asked that you synthesize one that works for you in your context, and I offered one as the working definition for the class**

Holism

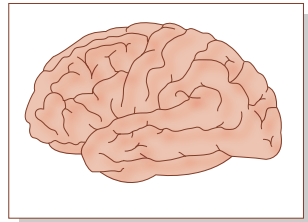


Figure by MIT OCW.

- **Of the Whole**

  To think holistically is to encompass all aspects of the task at hand, taking into account the influences and consequences of anything that might interact with the task.

¿ Example: What is the Whole? (while architecting a product or system)

Holism – Assignment (for life)

- **Become a holistic thinker!**
- **Read - Talk - Think - Listen**
- **Holistic thinking exercise**
  - **Be ready for each class**
  - **Be ready for each day of your life!**
  - **Focus on *Global Forces* in business environment**
- **What should the foci be this month?**

Principles, Methods, Tools

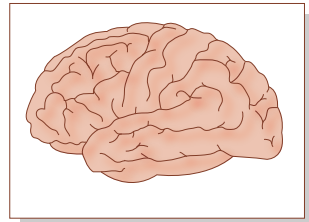


Figure by MIT OCW.

- **Principles are the underlying and long enduring fundamentals that are always (or almost always) valid.**
- **Methods are the organization of approaches and tasks to achieve a concrete end, which should be solidly grounded on principles, and which are usually or often applicable.**
- **Tools are the contemporary ways to facilitate process, and sometimes applicable.**

Examples: Principles, Methods, Tools

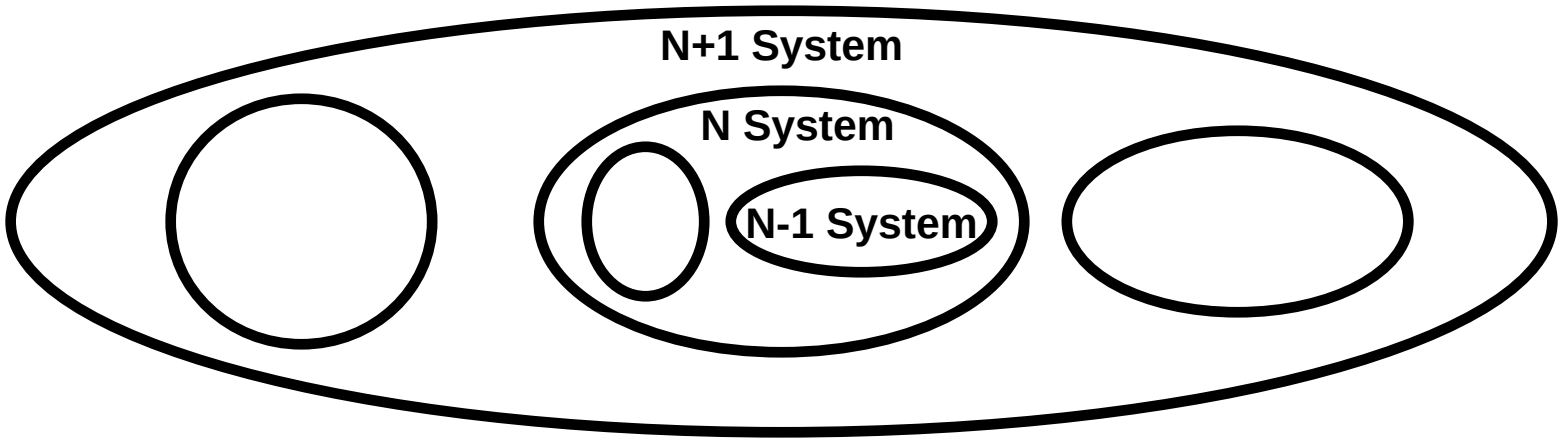
	Time Scale	Science	Engineering Science
Principle			
Method			
Tool			

Examples: Principles, Methods, Tools

	Architecture Of Products	Product Development Processes	Product Organizations
Principle			
Method			
Tool			

A Principles – Example

- **Every system operates as an element of a larger system and is itself composed of smaller systems**



How could you improve this principle?

Principles – Assignment

- **A *Journal of Architecting Principles* should be completed by each student**
  - **Capture ideas from *all* SDM subjects, other readings and from life experience**
  - **As a target, codify 8 - 15 *principles* of system architecture (i.e. truths that are fundamental and almost always valid)**
  - **Due at the end of the subject (in Dec.)**
  - **Should contain**
    - **The principle (descriptive and prescriptive)**
    - **Attribution**
    - **Short description or application**
- **Principle No. 1 should be: What is good architecture.**

Principle Submission

- **“Tag Line Version”**
- **Descriptive version**
- **Prescriptive version**
- **Text which explains the principle, how it would apply to your enterprise**
- **Citation where it came from**

- **So “every systems operates as a part of a larger system, …” is what: descriptive or prescriptive? What would the other one be?**

The Product Development Process

- **The inclusive process of creating a new or modified product, bringing it to “market” and supporting its life-cycle**

- **It is important to understand the role of architecting in the PDP, and the commonality of good practice in our professions**

PDP - Assignment (#3)

Determine what is common to all PDP's, and what causes them to be different:

- **Compare each of the PDP's that you benchmark and identify the elemental "steps" (there may be 20 to 40 of these). Identify the steps that are common to all or most of your PDP. Also examine the sequence of these steps.**
- **Synthesize the common PDP steps into one reference process.**
- **Examine the differences between the reference process and the original benchmark examples. Try to explain why the differences occur.**
- **Identify the contribution of architecting to the PDP, and the influence of the other parts of the PDP on architecting.**

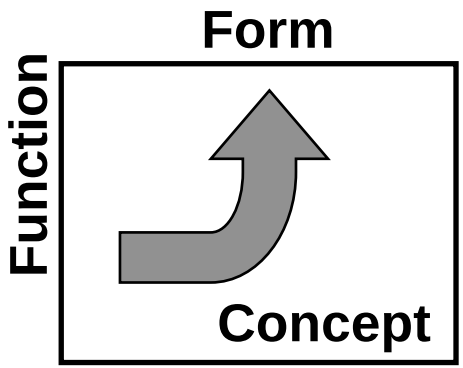
Other Definitions – Assignment (#1)

- **Without clear definitions, statements like "architecting complex product/systems to deliver value" will just be stratego-babble**
- **Your group should develop a consensus definition of:**
  - **System**
  - **Complex**
  - **Value**
  - **Product**
- **Principle/Method/Tool (give examples, not definitions)**

Cite 1-3 references and your synthesized definition. Give an illustrative example.

Architecture

- **Consists of:**
  - **Function**
  - **Related by Concept**
  - **To <u>Form</u>**



Form - Defined

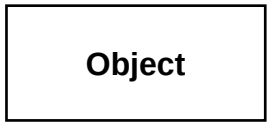
- **The physical/informational embodiment which *exists*, or has the potential to exist**
- **Is what the system "is"**
- **The *sum* of the elements, which are segments (of the whole of) the form**
- **The structure of form - the formal relationships among the elements**
- **Is a system/product attribute**

Form is Elements + Structure

Form - Described

- **Is created by the architect**
- **Is in a solution specific domain**
- **Can be decomposed into physical/informational elements - the *decompositional* view**
- **Elements are connected at interfaces. The interfaces define the structure - the *structural* view**
- **Is the thing that executes function**
- **Is the thing that is eventually implemented (built, written, composed, manufactured, etc.)**
- **Is the thing that is eventually operated (run, repaired, updated, retired, etc.)**

Objects



- **Defined: An object is that which has the potential of stable, unconditional existence for some positive duration of time**
- **Can be physical: visible or tangible and stable in form**
- **Can be informational: anything that can be apprehended intellectually**
- **Objects have states (which can be changed by processes)**
- **Objects are linked to nouns**

Decomposition of a System

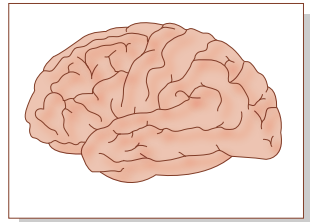
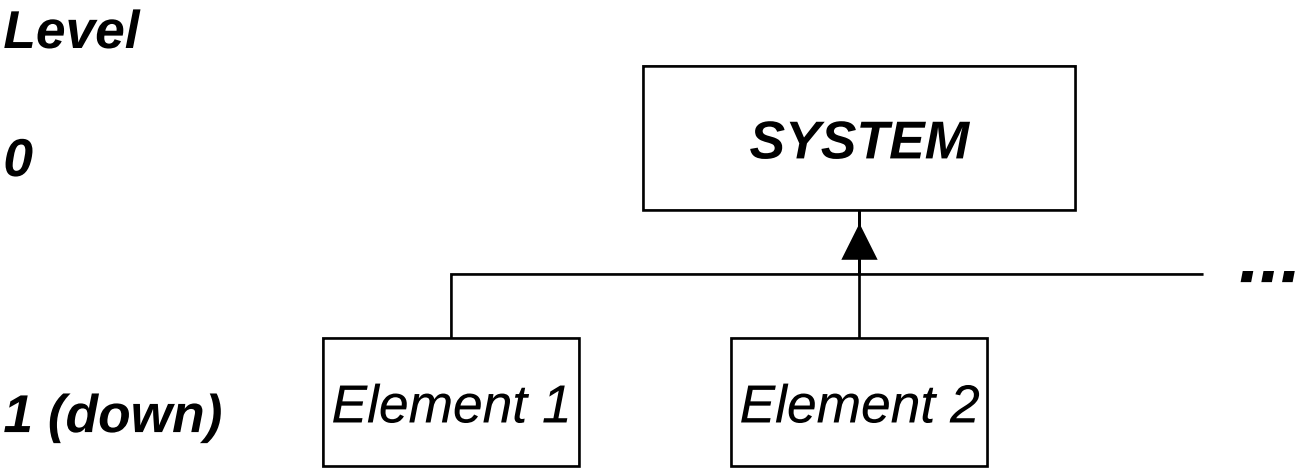
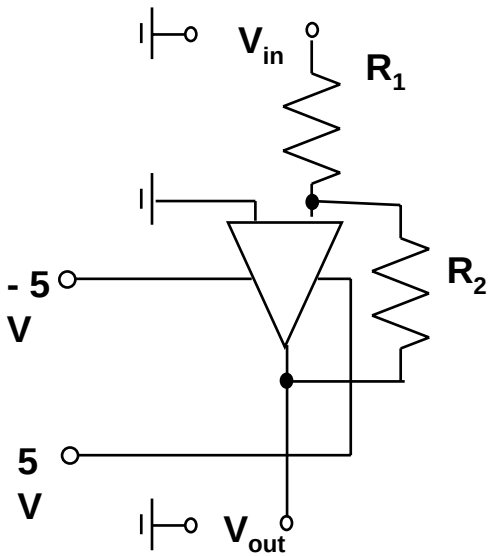


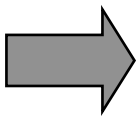
Figure by MIT OCW.

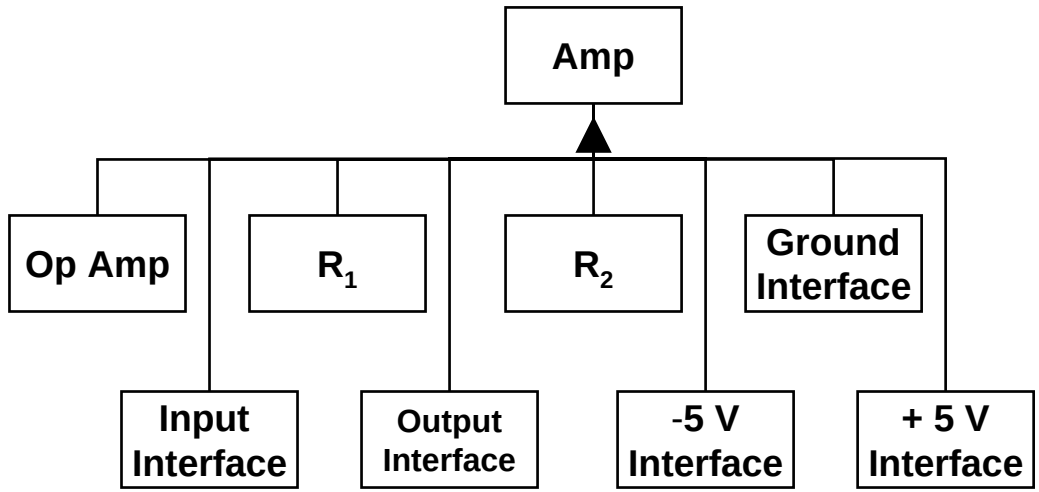


- Decomposition is the division into smaller constituents
- The system object at level 0 decomposes to the element objects at level 1
- The element objects at level 1 aggregate to the system
- This is the *whole - part relationship*, so common that it has its own symbol ▲

Op Amp - Decompositional View







Plus connectors? Ground?

Could you build and amp from such information?
Could you understand how it is laid out?
Could you understand how it works?
Not much real information in the decompositional view!

¿ What is the Form of Simple Systems?

- **Each group should examine one of the examples, and describe the *form* of the system**
- **Describe the elements objects that make up the system object**

Example Systems:

- Paper coffee cup
- Pen (ball point or felt tip)
- Notebook or pad of paper
- Stop sign
- Simple code

“Software” Code

```
n=0
start at first Ø
while Ø remains without an X
        print X at location of Ø
        n=n+1
end_of_while
write n
```

Elements of Form

- For simple physical systems, the elements for form can be broken down until the smallest useful "atomic unit" is reached: paper cone, plastic tube, sheet of paper
- For simple information systems, the elements of form are a bit more abstract, but it is most useful to stop when a coherent instruction is reached
- For instructional systems, the *instruction* is an element of form - what the instruction does is its function, and will be discussed in the next lecture
  - n = n+1
  - STOP

Courtesy of ENPHO. Used with permission.

Abstraction

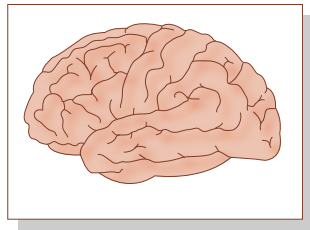
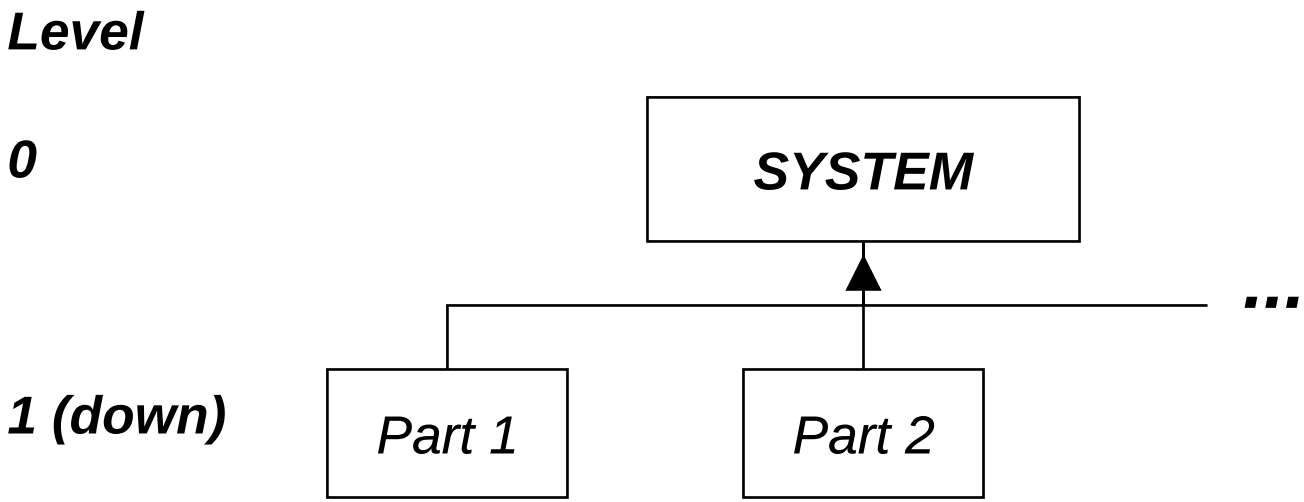


Figure by MIT OCW.

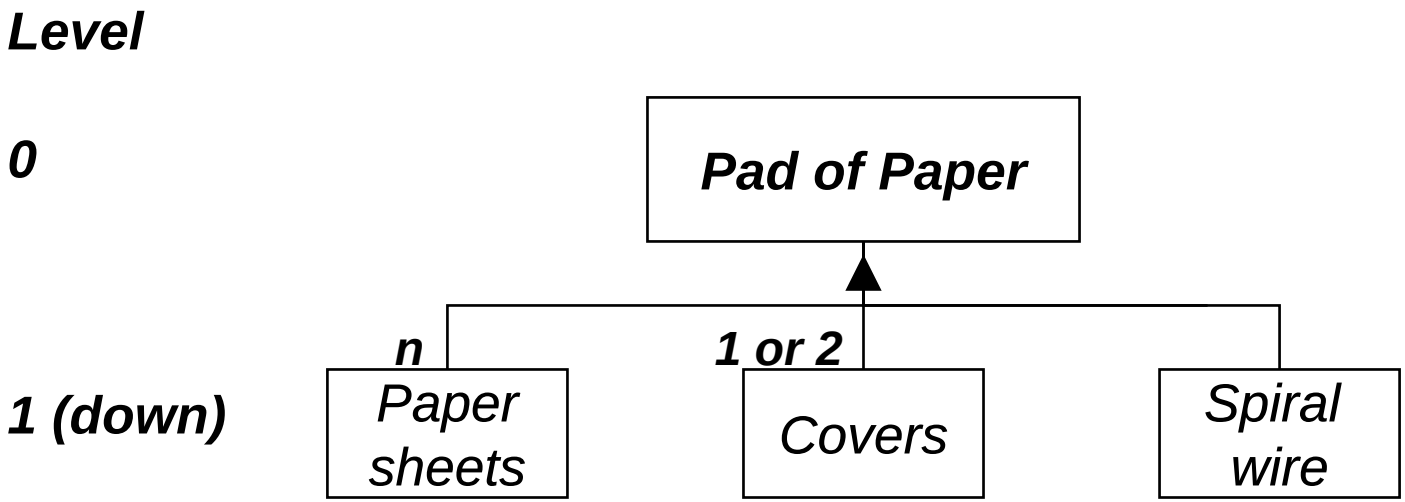
- **Abstraction defined as:**
  - **expression of quality apart from the object**
  - **having only the intrinsic nature rather than the form**
- **Abstraction can be used in both function and form**
- **Abstraction can be used to characterize and hide more detailed structure and behavior within them, allowing simpler representation of the "surface"**
- **Examples: cup, pen, routine_name**

Decompositional View of a Simple System



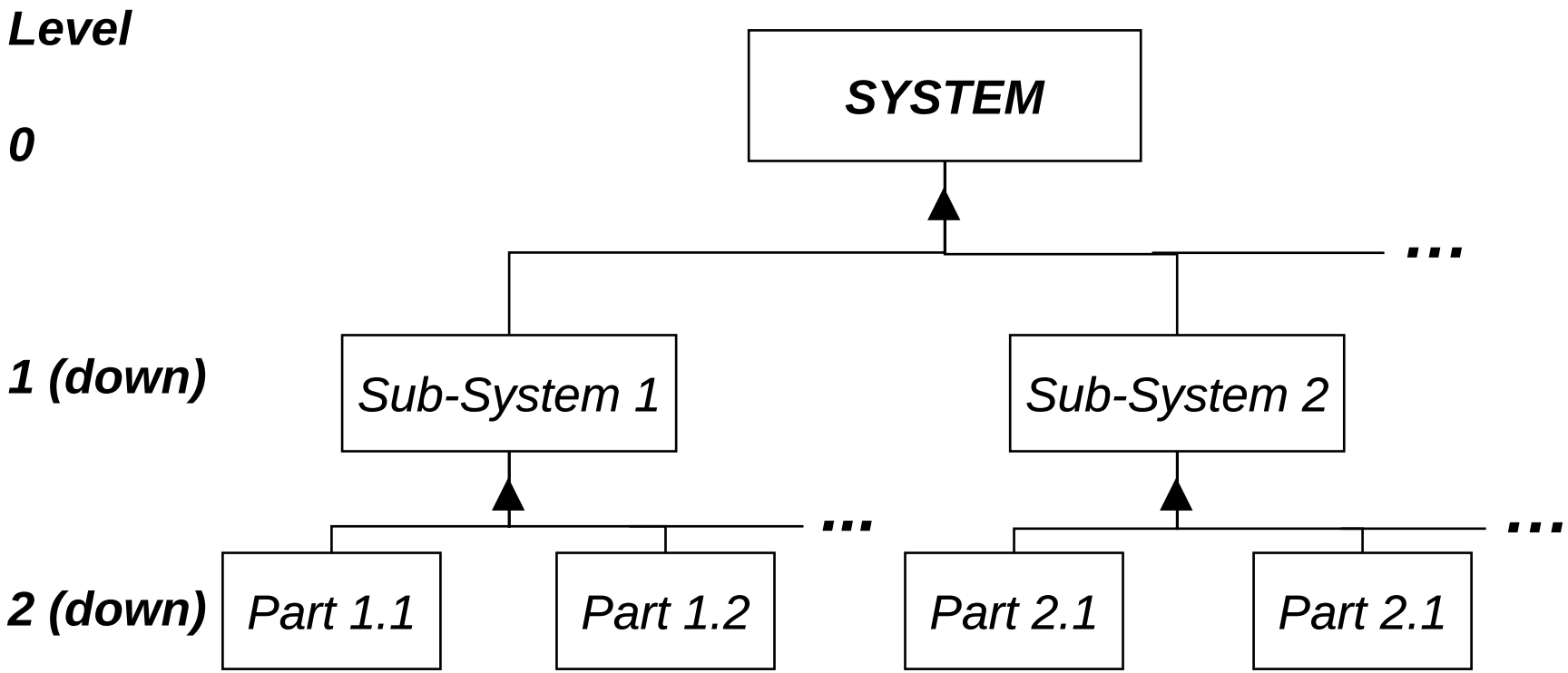
- Theoretically 5-9 elements (7+/- 2), actually 2 to about 9-12
- At level 1 we encounter real or atomic parts (a matter of somewhat arbitrary definitions)
- Tree structure is symbolic of the decompositional view, and suggests what element aggregate to which higher lever element
- Does not represent the actual structural connectivity of the elements (the structure)

Decompositional View of a Simple System - Example



- **At level 1 we encounter real or atomic parts (a matter of somewhat arbitrary definitions)**

Decompositional view of a Medium System



Decompositional View of a Medium System

- Theoretically 25-81 elements $(7+/-2)^2$, actually about 9-12 to about 60-90
- At level 2, we encounter atomic parts
- Least ambiguous objects are defined at levels are 0 and 2
- Intervening level 1 might be real subsystems modules, abstractions, or both
- Actual structural connectivity can occur at either level 1 or 2

Decompositional View of a More Complex System

- Theoretically 125+ elements $(7\text{-}2)^3$, actually about 60-90+
- Same drawing as a medium system - except level 2 is no longer made up of atomic parts, but rather further abstractions or modules
- There may be many layers below level 2, which an observer at level 0 barely understands
- Actual structural connectivity can occur at any level

¿ What is the Structure of Form of Simple Systems?

- **Each group should examine one of the examples, and describe the *form* of the system**

- **Describe the structure among the element objects that make up the system object**

Example Systems:

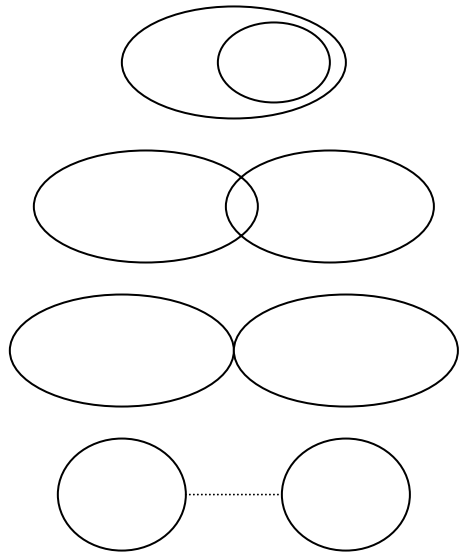
- **Paper coffee cup**
- **Pen (ball point or felt tip)**
- **Notebook or pad of paper**
- **Stop sign**
- **Simple code**

Classes of Structural Connections

- **Connections that are strictly descriptions of *form*:**
  - **Some notion of spatial location, proximity or topology (e.g. is next to)**
  - **Some notion of previous assembly/implementation process (e.g. "connected to" means long ago a connecting process took place)**
- **Connections that are description of *function* while operating**

Spatial/Topological Structural Connections

- **One kind of information that can be encoded in structural links is relative spatial location (above, below, to the right of, aligned with, etc.) plus topology:**
  - **Is contained in, surrounded by, encompasses, encircles**
  - **Overlaps with, shares part of**
  - **Is adjacent to, touches**
  - **Is separate from (near, far, no apparent relation at all)**
- **Issues of Form, representing positioning that has taken place *in the past***



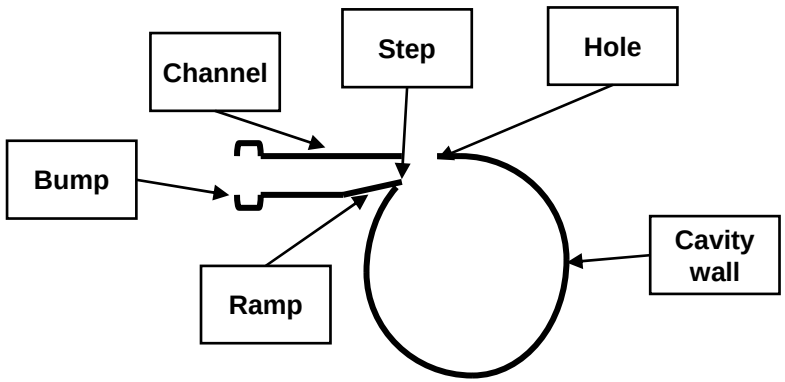
This information is conventionally in a schematic or layout drawing

Assembly/Implementation Structural Connections

- **Another kind of information that can be encoded in structural links is information about how the objects were assembled, manufactured, coded, written, etc.:**
  - **Is bonded to, welded to, soldered to, glued to**
  - **Is bolted, fastened**
  - **Pressed against, inserted**
  - **Is compiled with**
- **Issues of form, represent implementation that has taken place *in the past***

This information is conventionally in an assembly drawing

Whistle - Objects as Elements of Form



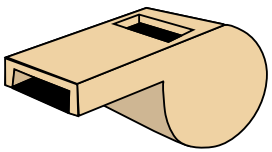
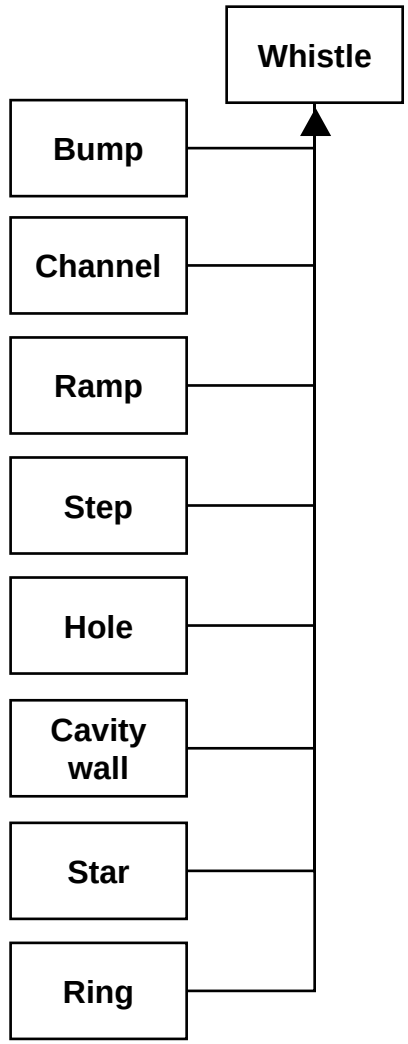
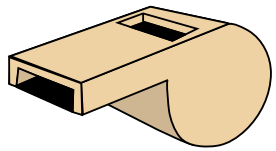


Figure by MIT OCW.

Can also be represented as a list



Structure of Elements - Whistle



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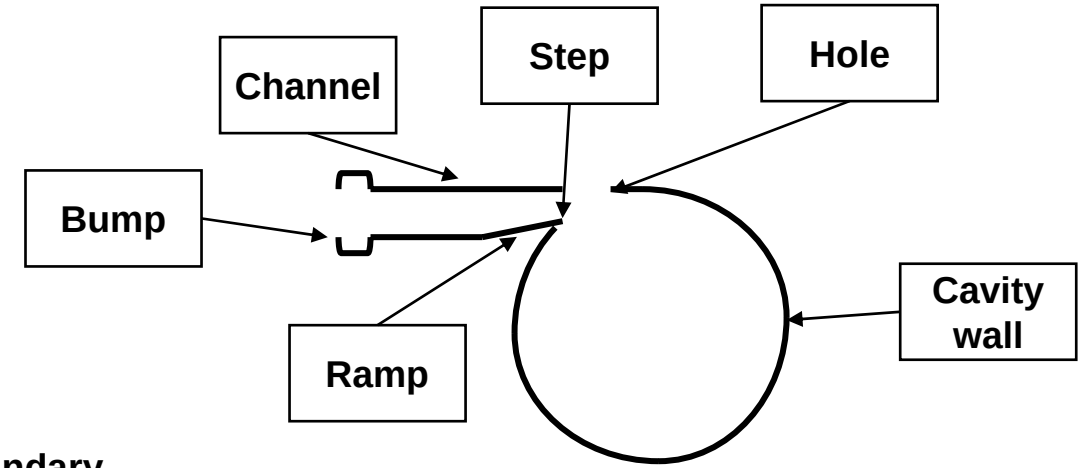
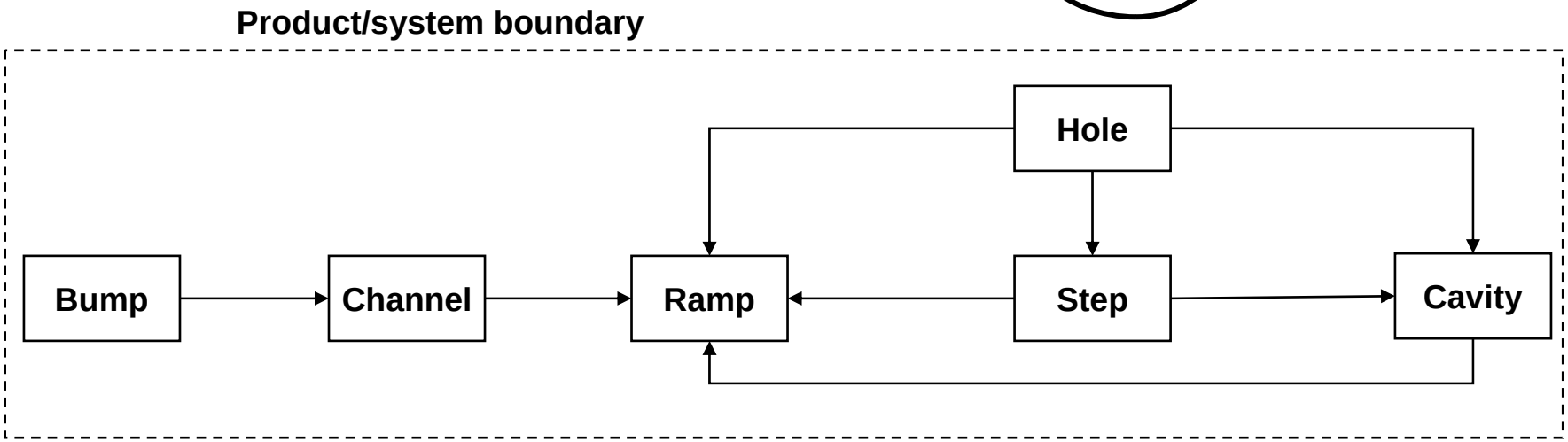
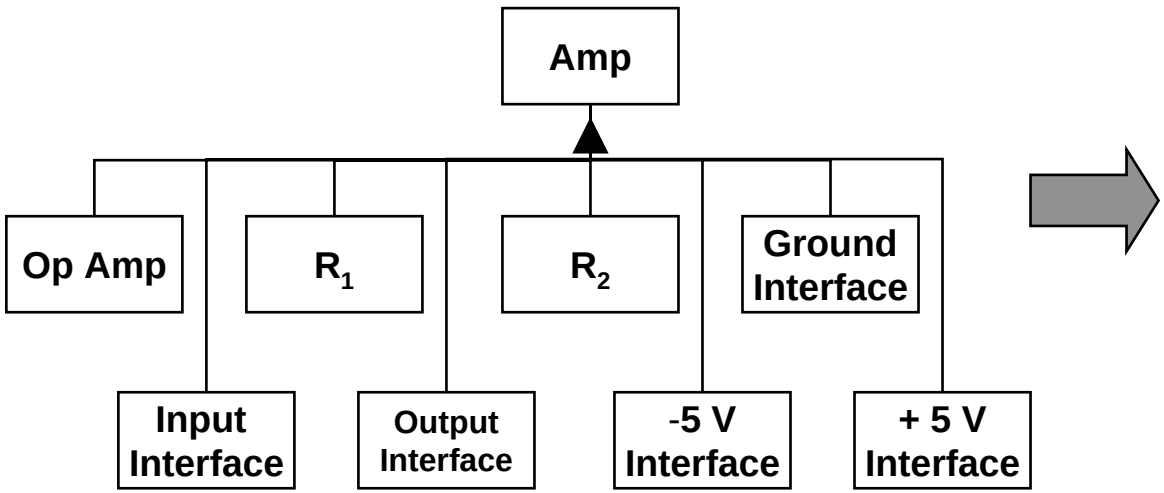




What do these lines mean??

Op Amp - Decompositional - List

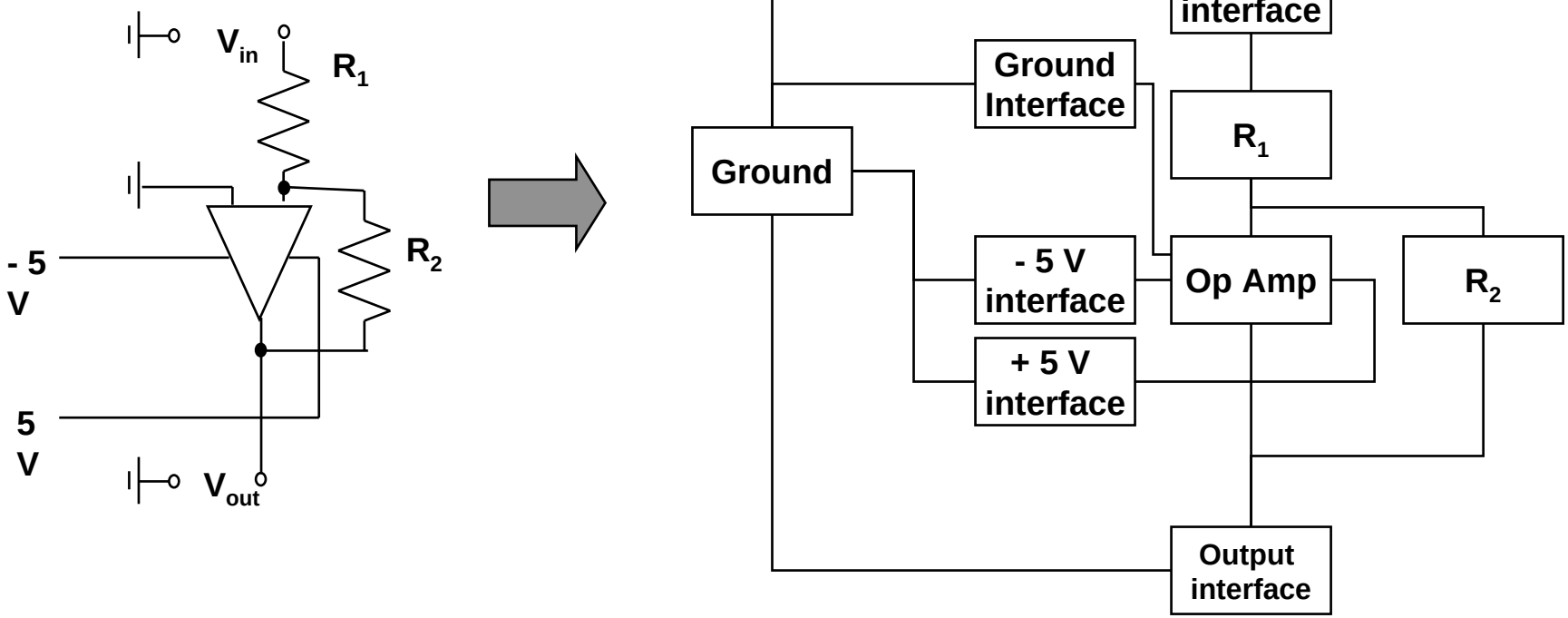


Amp:

Op Amp
R_1
R_2
Ground Int.
Input Int.
Output Int.
-5 V Int.
+5 V Int.
Connectors?
Gound?

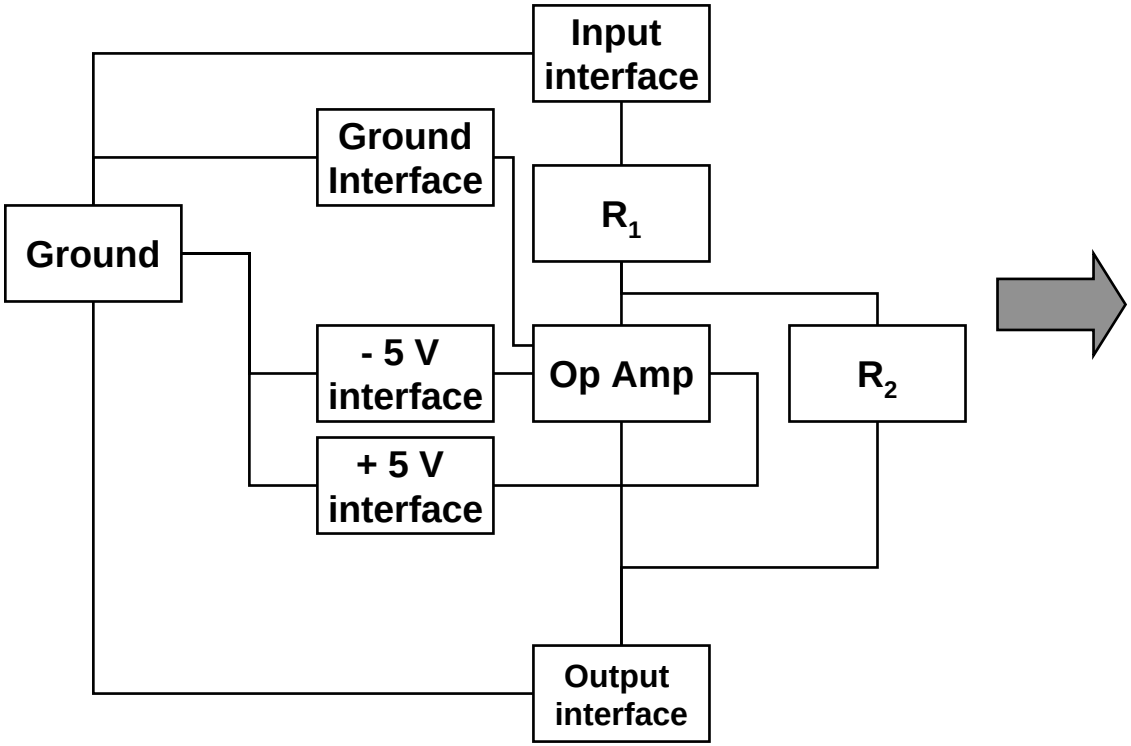
Alternative to graphical representation of the decompositional view is the list representation

Op Amp - Structural View - Graphical



What do these lines mean?
Is this structure describing form?

Op Amp - Structural View - List?



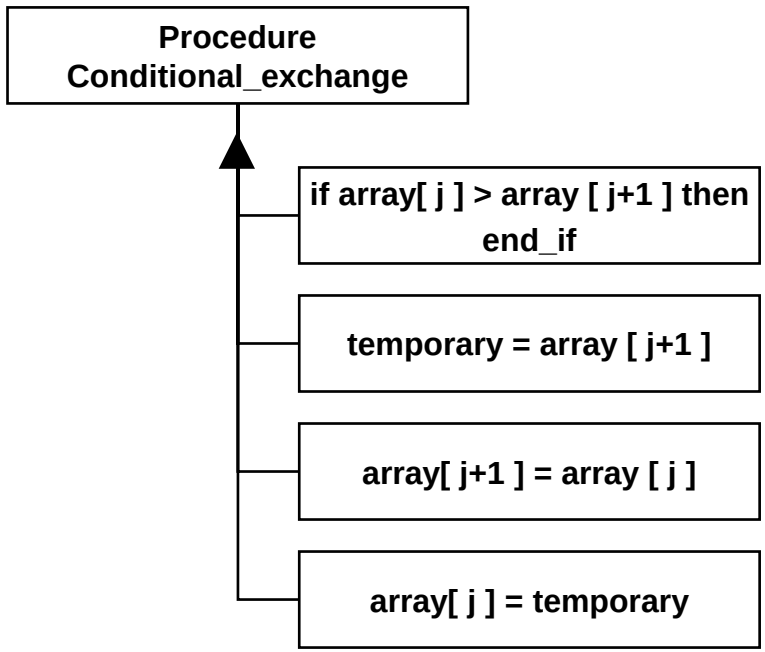
Amp: ?????????

Op Amp
R_1
R_2
Ground interface
Ground?
Input Int.
Output Int.
-5 V Int.
+5 V Int.
Connectors?

What is an appropriate way to represent structural information shown in graphic representation in a list representation?

Software Code - Decompositional View

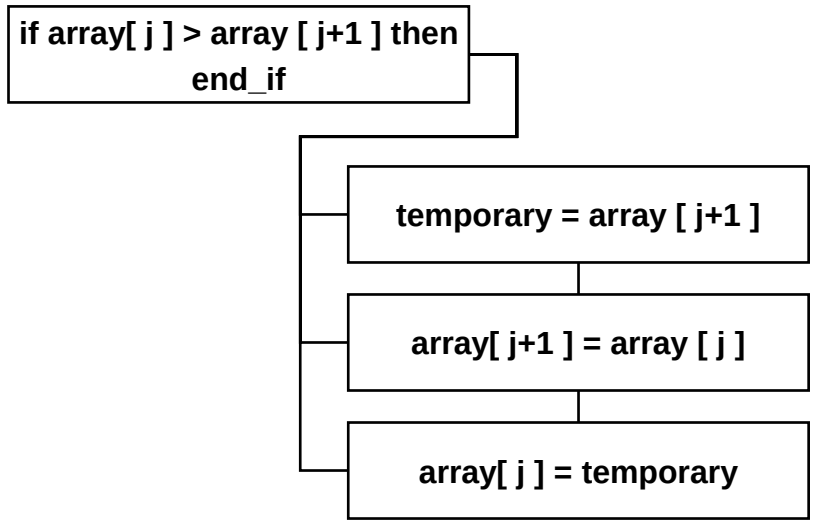
```
if array[ j ] > array [ j+1 ] then
temporary = array [ j+1 ]
array[ j+1 ] = array [ j ]
array[ j ] = temporary
end if
```



Software is often already in a list representation. However for more complex code, something like a decompositional view is often all that is easily available

Software Code - Structural View

```
if array[ j ] > array [ j+1 ] then
temporary = array [ j+1 ]
array[ j+1 ] = array [ j ]
array[ j ] = temporary
end if
```



For software what is the appropriate way to represent structure <u>of form</u> in the list and graphical representations?

Issues Raised

- How do you identify form independent of function?
- How do you define the atomic part level? For hardware? For software?
- Can you “decompose” an integral part?
- How do you represent the structural interconnections of the elements, as opposed to their “membership” in a system?
- N occurrences of an element - count once or N times?
- Connectors and interface elements - count as a separate element - or combined with other elements?

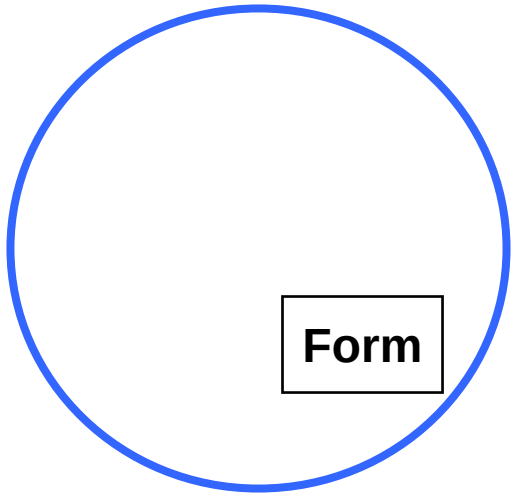
Disciplines have their own tradition of representing form (decomposition and structure), what is it in your discipline?

Summary - Form

- **The physical/informational embodiment which exists, or has the potential to exist**
- **The sum of elements (objects) related through structure**
- **Is a system/product attribute created by the architect**
- **Is what executes function**
- **Is implemented and operated**
- **Is decomposed (potentially in layers), the number of which determine: simple -to- complicated**
- **Is decomposed until the atomic part in encountered (a matter of definition)**

Complete description of form requires definition of both *elements* and *structure*

Summary to Date



Architecture?

Form = Elements + Structure

Upstream Processes

- General
- Technology Infusion
  - Finding
  - Forecasting
  - Transferring
  - Infusing

Where Does an Architect Find Upstream Wisdom?

- **Customer**
  market need or opportunity
- **Technology**
  what's available or might be
- **The Company**
  corporate strategy, competency
- **Business Environment**
  competition, global economic, international markets, worldwide suppliers, etc.

Upstream Wisdom From SDM

- **Customer - a bit this month, marketing subject, and system engineering subject**
- **Technology - some this month, 2 design electives, informal network, Management of Technology elective**
- **The Company - some in this subject, System Project Management, leadership exercises, corporate strategy elective**
- **Business Environment - marketing subject, your self education!**

Three Questions Central to Technology Assessment and Infusion

- **What is the forecast for the *technology*?**
  - **Where is it? What can it do?**
  - **What is its readiness?**
  - **When will it be "ready"?**
- **Does it address a *customer* need?**
  - **Will it infuse value in the product?**
- **Can our *company* exploit the technology?**
  - **Is it within our competence and its extensions?**
  - **Does our organizational strategy support it?**

Finding and Infusing Technology

- **Finding Technology**
- **Understanding, Assessing and Forecasting**
- **Transferring**
- **Infusing**

Where Do You Find Technology?

- You invent it
- Your existing products
- Competitors' products
- Your corporate R&D
- Competitors' corporate R&D
- Universities
- Foreign sources
- Government labs
- Suppliers
- Small companies
- Where else?

How Do You Find Technology?

- Thinking, reading
- Visits
- Papers, articles, reports
- Conferences, shows
- Personal contacts, networks
- Seminars
- How else?

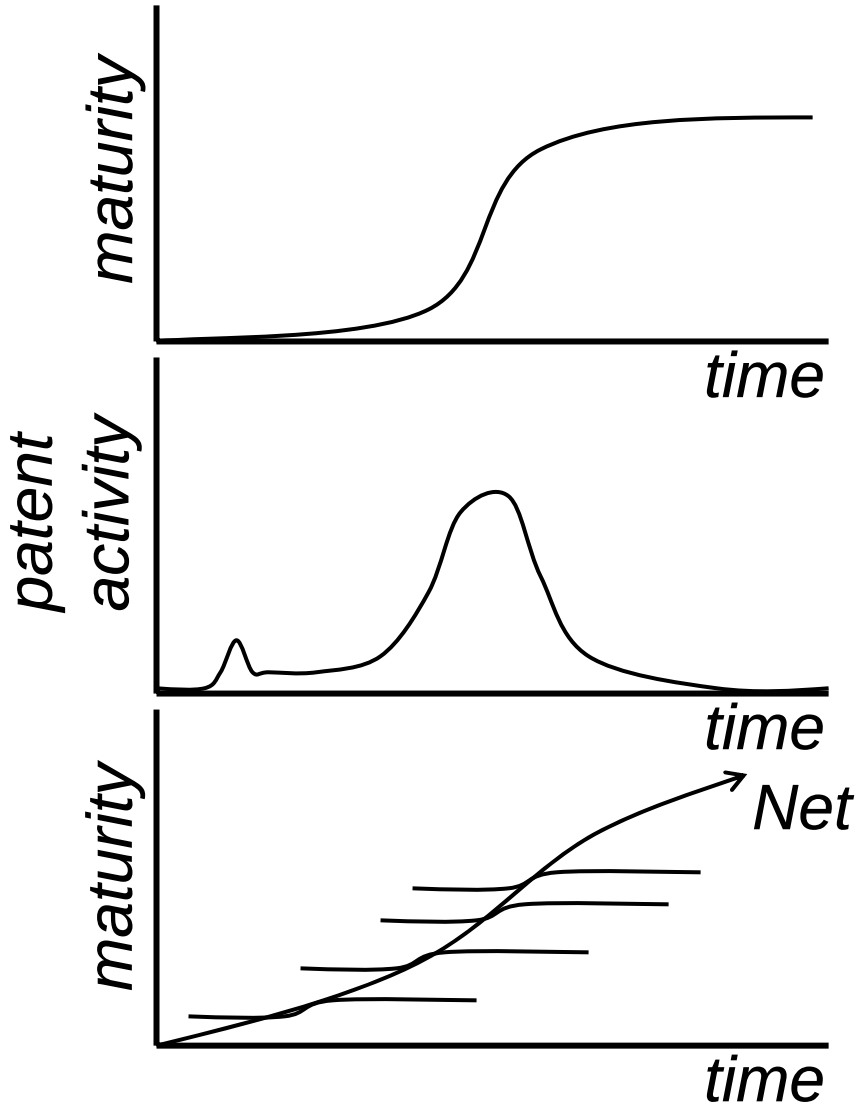
Understanding Assessing, Forecasting

- What is it, how does it work?
  - New “physics”, manufacturing
  - Clever design or combination
- What might it do?
- How does it relate to alternatives?
- How mature is it?
  - What combinations of time, money are required
  - How much further can existing team take it?
- What is Intellectual Property (IP) status?
- What else?

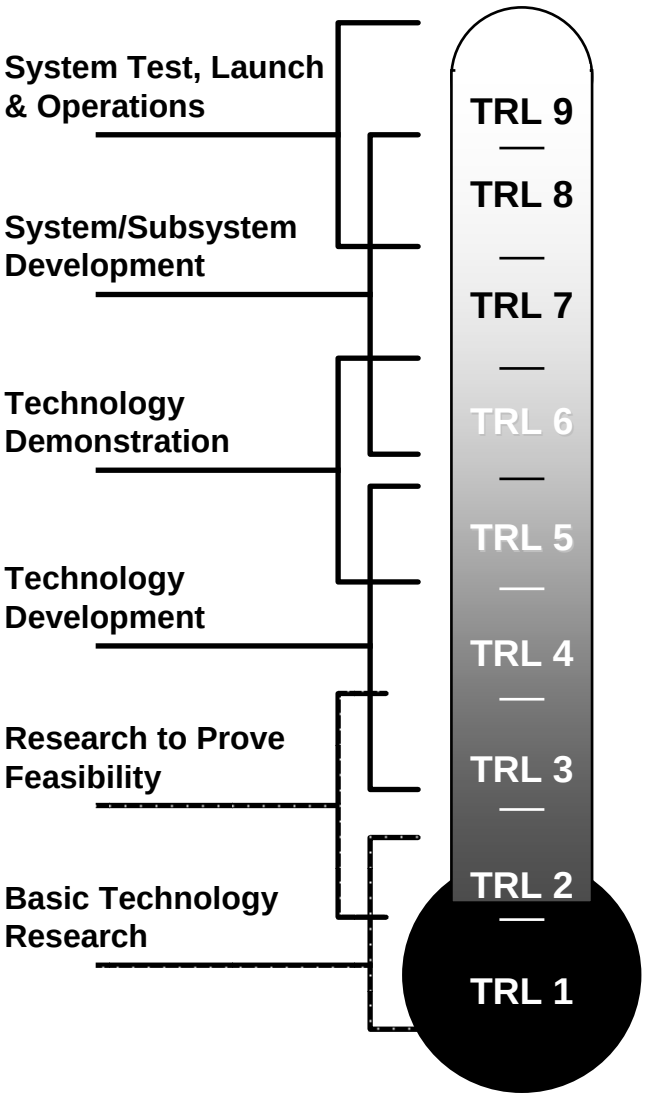
Technology Maturation Model

- **Single technology the "S" curve**

- **Platform technology**



Technology Readiness Levels (TRLs)



Actual system "flight proven" through successful mission operations
Actual system completed and "flight qualified" through test and demonstration (Ground or Flight)
System prototype demonstration in a space environment
System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
Component and/or breadboard validation in relevant environment
Component and/or breadboard validation in laboratory environment
Analytical and experimental critical function and/or characteristic proof-of-concept
Technology concept and/or application formulated
Basic principles observed and reported

Courtesy of NASA.

Transferring Technology

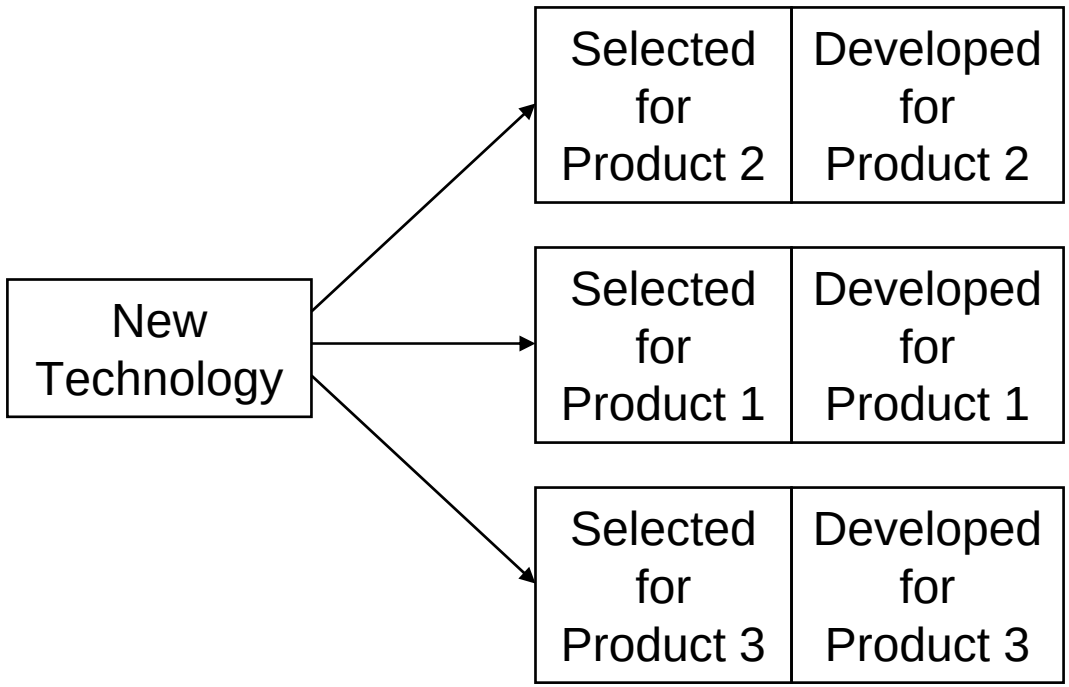
- Corporate alliances and partnerships
- Corporate acquisitions
- Hiring
- Inclusion in supply chain
- Small company as intermediary
- How else?

People are best

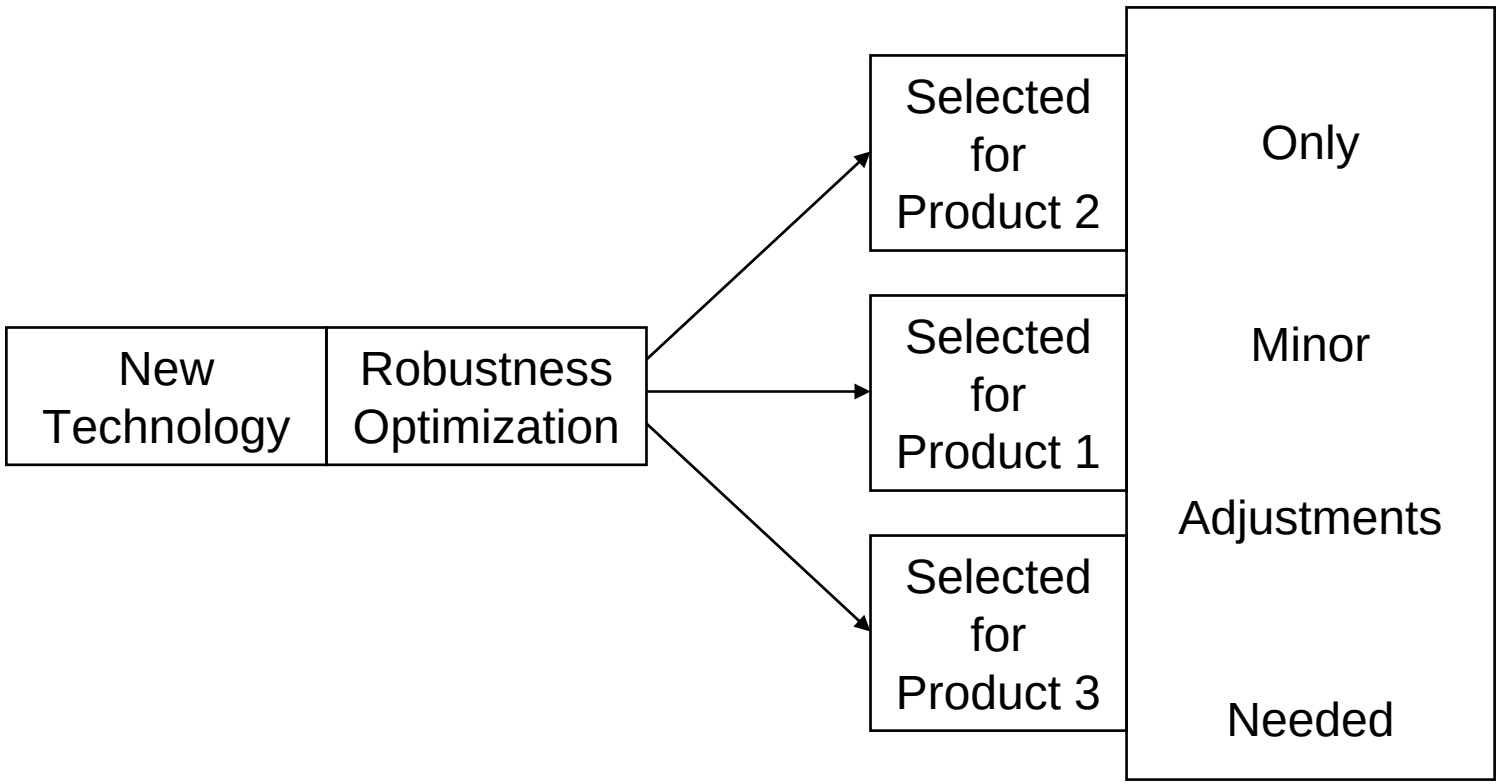
Infusing Technology

- **Into future product thinking - to create new markets**
- **Into new platforms - to service new products**
- **Into new products**
- **Into existing products**

Infusion of Non-robust Technology



Flexible Infusion of Robust Technology



Technology Search - Assignment #1

- **Form organic groups of 3±1 members of similar technical interests**
- **Conduct search for 3 technologies**
- **Select one, and analyze it relative to existing technology**
- **Make a recommendation**
- **Write a memo that can be submitted to your real boss!**

Assignments for Next Time:

- **Opportunity Set 1: Definitions**
- **Opportunity Set 2a: Form of simple systems**
- **Holistic thinking: Be prepared to discuss current global topics in technical/scientific/economic/political spheres, and their impact on your enterprise**
- **Thought exercise: what is architecture, what is the architecture of common things, what is good architecture?**
- **Preparation for next class: read readings and be prepared to come and discuss critically (like in movies about law and business schools!)**