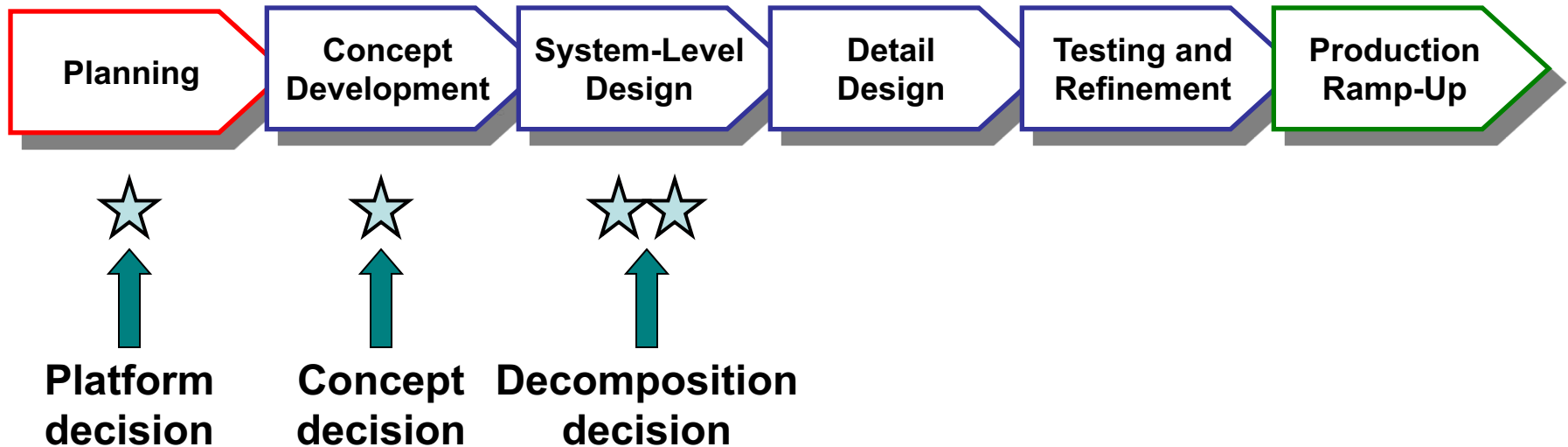# *Modular Design*

Chapter 9: Product Architecture

Product Design and Development
Fourth Edition
by Karl T. Ulrich and Steven D. Eppinger

Product Development Process

Planning	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up

Platform decision

Concept decision

Decomposition decision

Product architecture is determined early in the development process.

Product Architecture: Definition

The arrangement of functional elements into physical chunks which become the building blocks for the product or family of products.
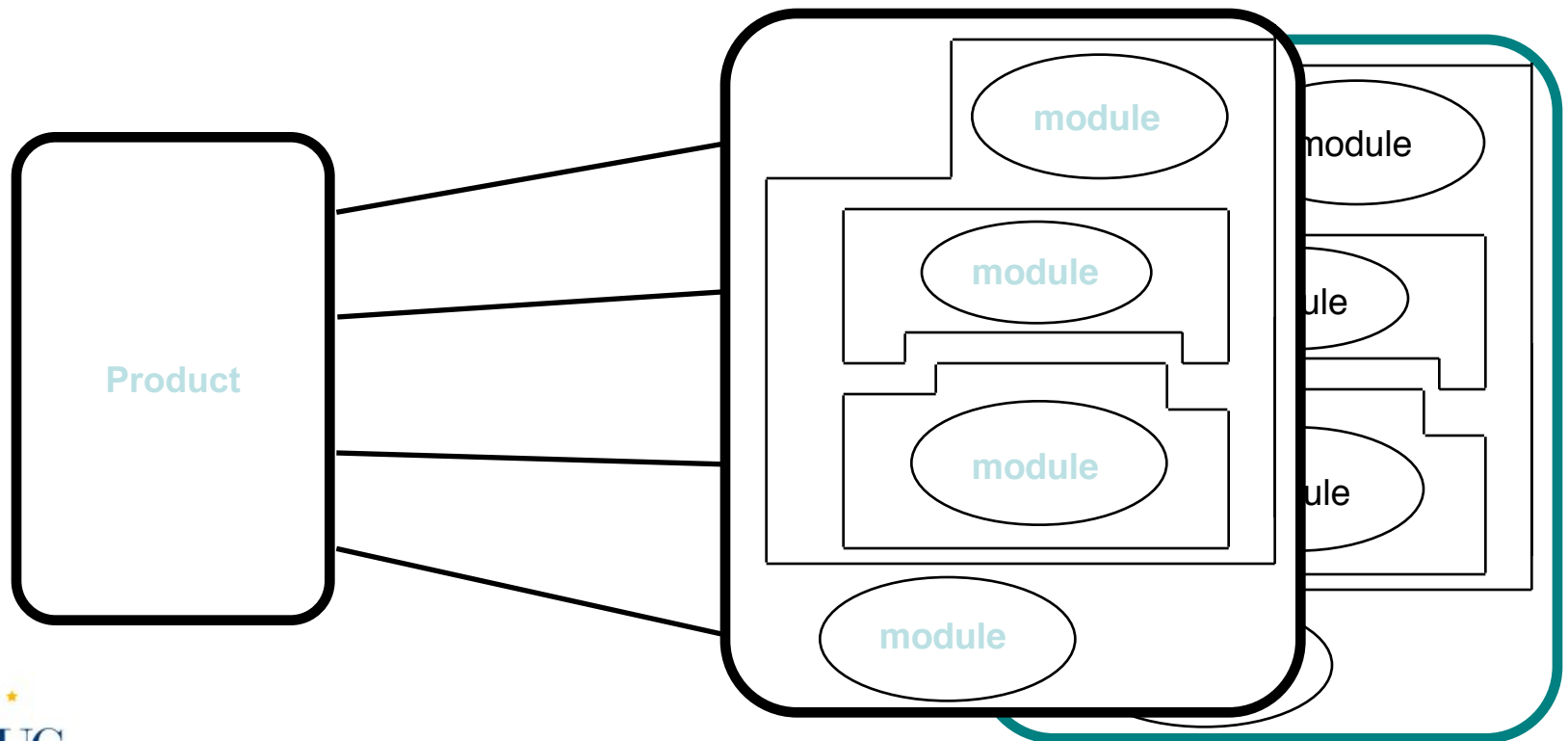
Aspects of Product Architecture

- Modularity
- Point of product differentiation

Importance of Product Architecture

- Decided early and drives design
- Impacts manufacturing cost
- Impacts product evolution
- Impacts organization structure of design teams

Modular Design Displays the Following Properties:

- Each physical chunk implements one or a few functional elements in their entirety
- The interactions between chunks are well defined (i.e. the interfaces are well defined)

Integral Product Architectures

- Functional elements are implemented by multiple chunks, or a chunk may implement many functions.

- Interactions between chunks are poorly defined.

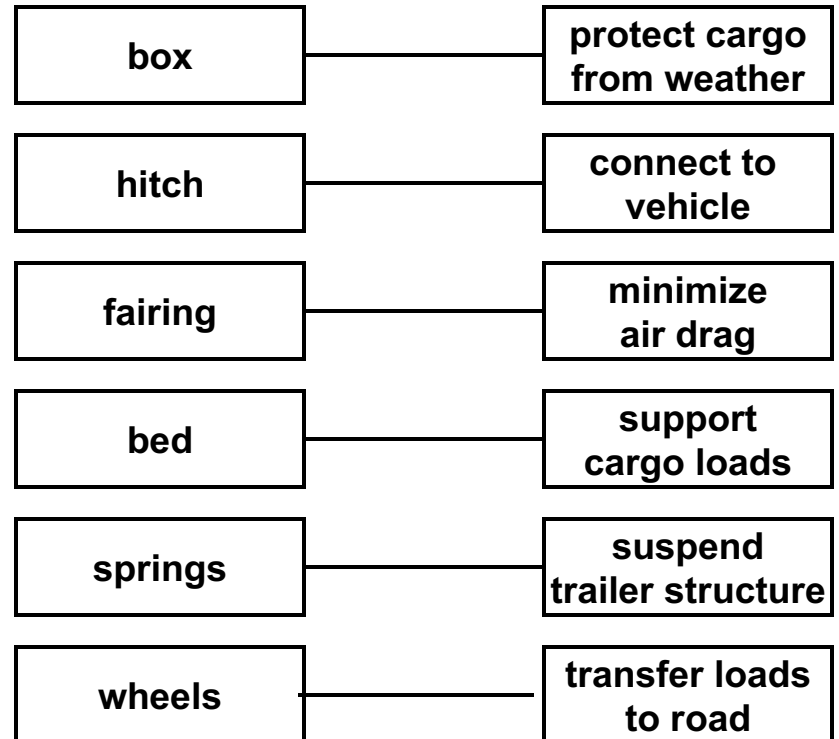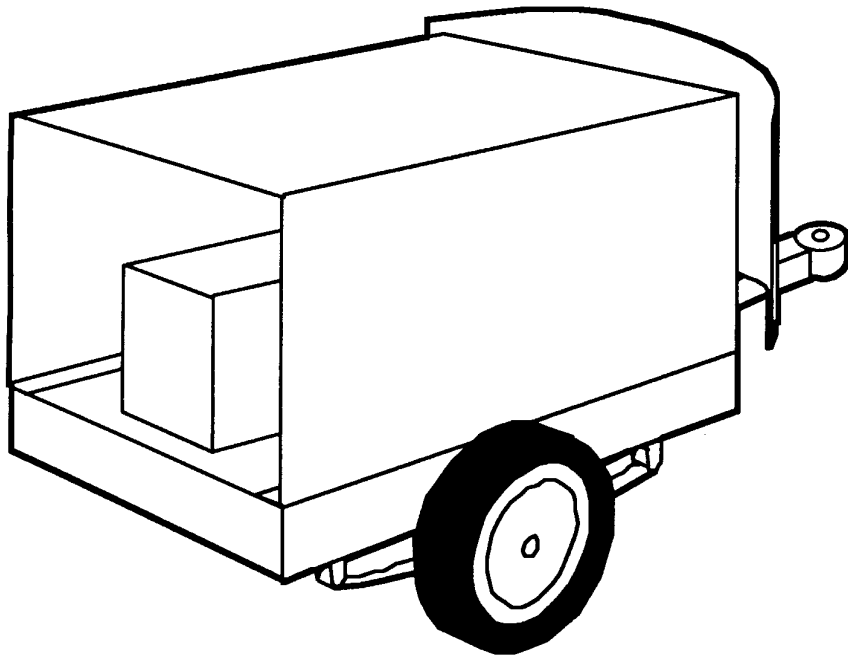- Integral architecture generally increases performance and reduces costs for any specific product model.
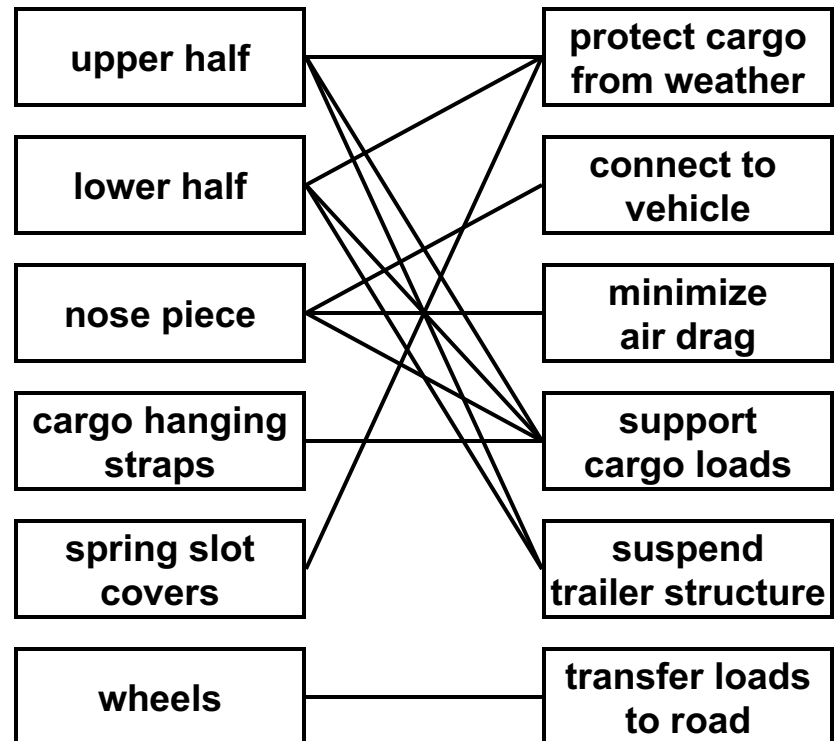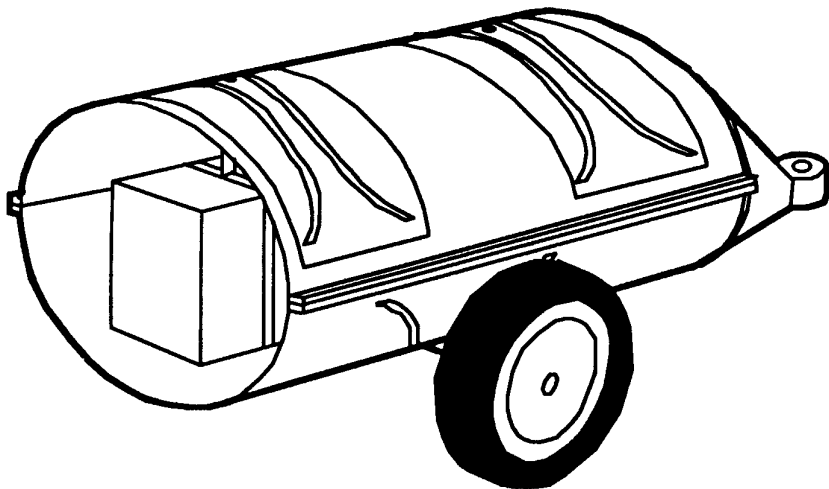
Modular or Integral?
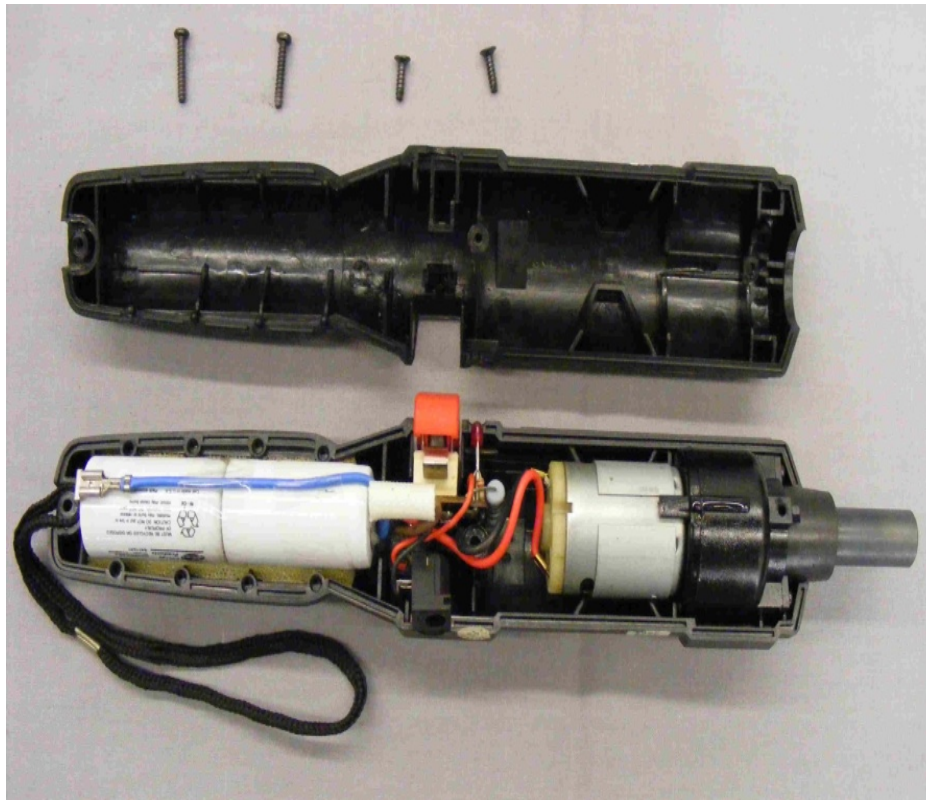
Examples

- Video Games
  - Modular: gaming systems (e.g. GameCube)
  - Integrated: stand-alone arcade games
- Power Supplies
  - Modular: power bricks
  - Integrated: on-board power converter

Trailer Example:
Modular Architecture

box	protect cargo from weather
hitch	connect to vehicle
fairing	minimize air drag
bed	support cargo loads
springs	suspend trailer structure
wheels	transfer loads to road

Trailer Example:
Integral Architecture

upper half	**protect cargo from weather**
lower half	**connect to vehicle**
nose piece	**minimize air drag**
cargo hanging straps	**support cargo loads**
spring slot covers	**suspend trailer structure**
wheels	**transfer loads to road**

Integral vs. Modular

Integral

- Higher system performance
- Tightly coupled design teams
- Hard to change

Modular

- Reduced performance
- Decoupled design teams
- Requires clear definition of interfaces
- Increased flexibility
- Accommodates made-to-order products
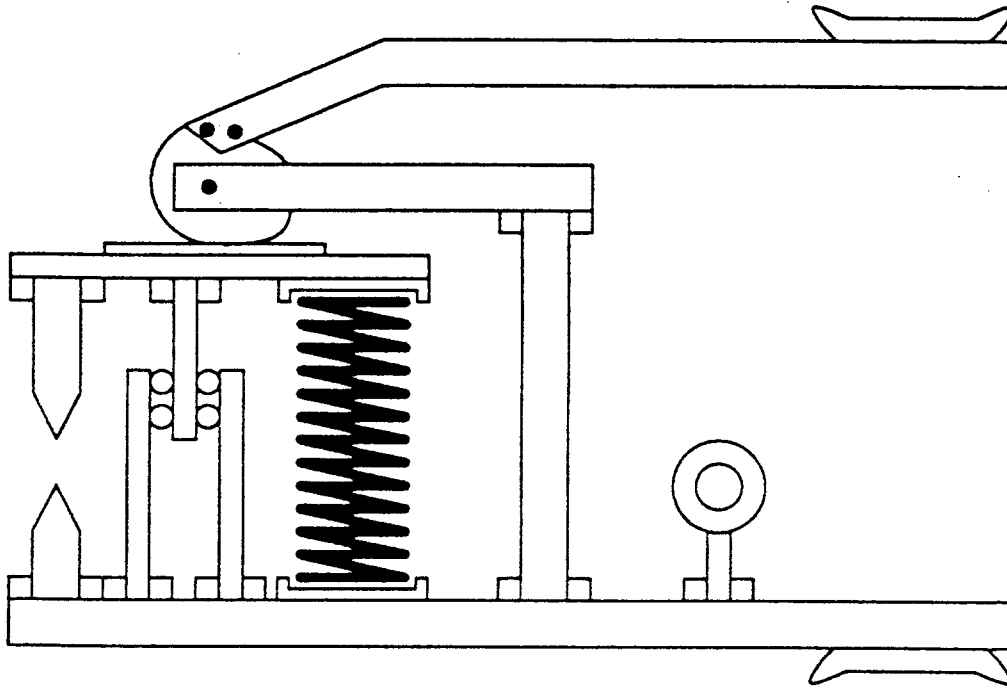
Integral vs. Modular

Integral

- Higher system performance
- Lower system cost (in large volume)
- Tightly coupled design teams
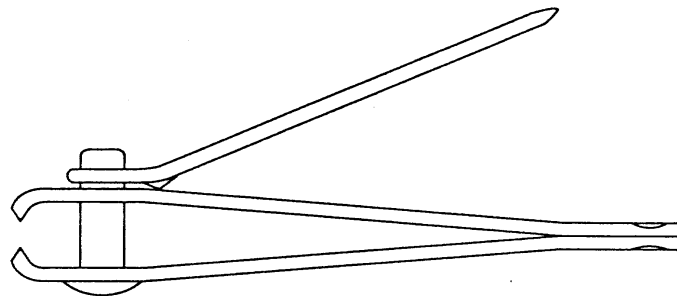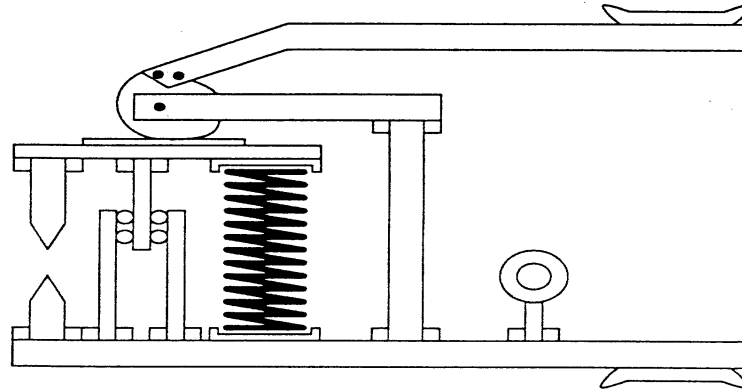- Expensive Tooling
- Hard to change

Modular

- Changeability
- Decoupled design teams
- Reduced performance
- Requires flexible manufacturing
- Cheaper at low volumes

What is this?

Nail Clippers?

Modular or Integral Architecture?

**Apple
iBook**

**Motorola StarTAC
Cellular Phone**

**Ford
Explorer**

**Rollerblade
In-Line Skates**

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Types of Modularity

- Slot-Modular Architecture

  – unique interfaces for attachment to a base element (e.g. pacemaker leads)

- Bus-Modular Architecture

  – common interfaces for attachment to a base element (e.g. USB connectors on a computer)

- Sectional-Modular Architecture

  – Common interfaces between elements without a base element (e.g. legos & piping)
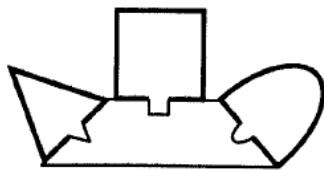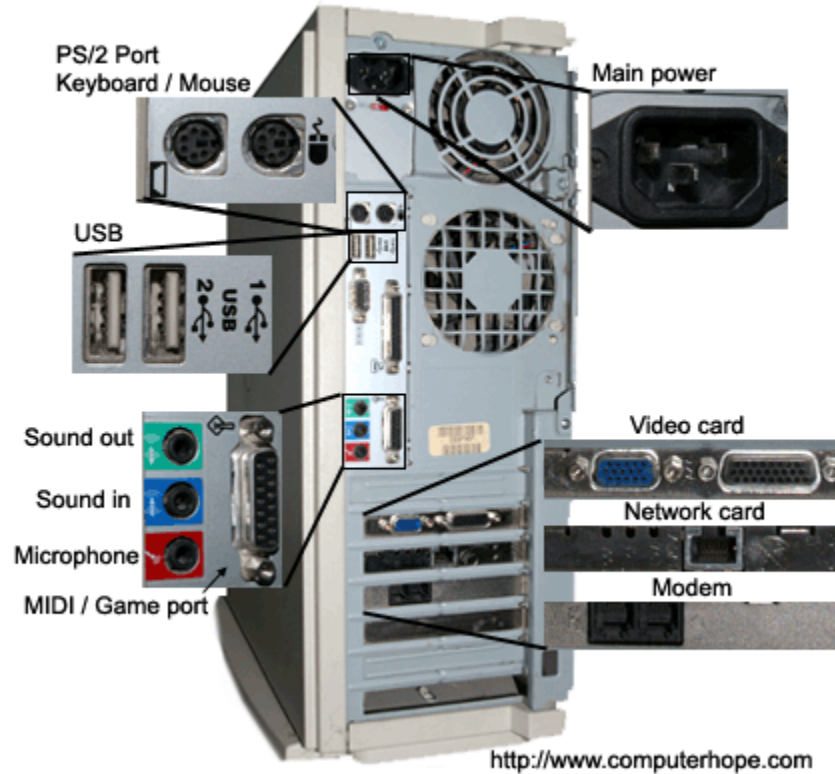
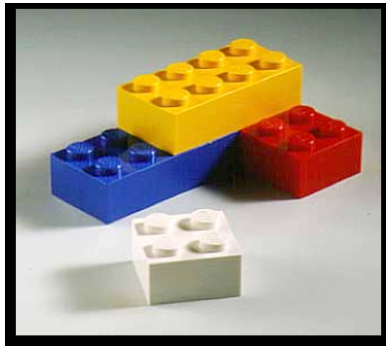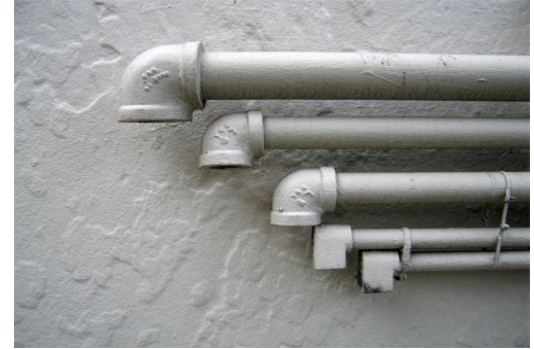Slot-modular architecture   Bus-modular architecture   Sectional-modular architecture

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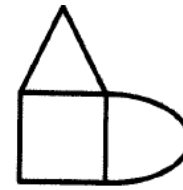
Back of computer case and each connection

Bus?
Slot?
Sectional?

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(COURTESY BRICKARTIST.COM)

Choosing the Product Architecture

Architecture decisions relate to product planning and concept development decisions:

- Product Change (copier toner, camera lenses)

- Product Variety (computers, automobiles)

- Standardization (motors, bearings, fasteners)

- Performance (racing bikes, fighter planes)

- Manufacturing Cost (disk drives, razors)

- Project Management (team capacity, skills)

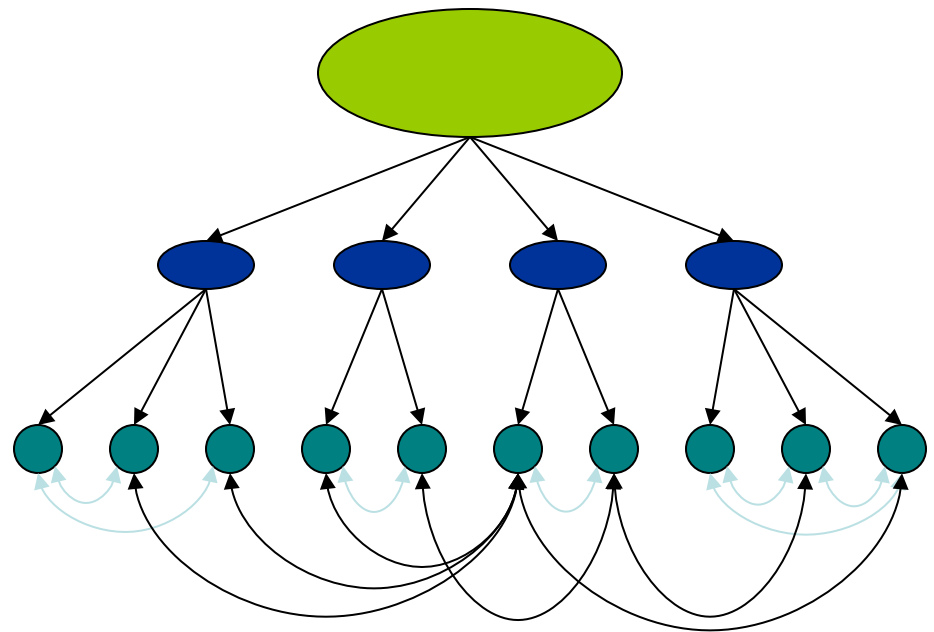- System Engineering (decomposition, integration)

The concepts of integral and modular apply at several levels:

- system

- sub-system

- component
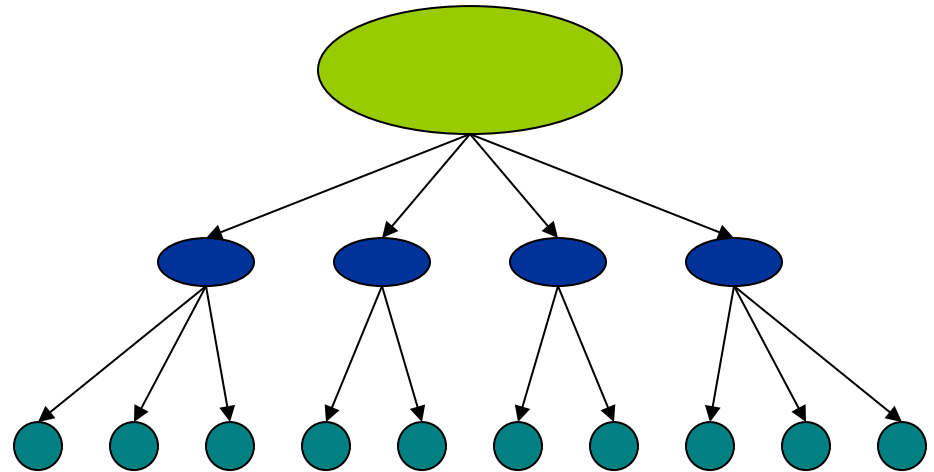
Product Architecture = Decomposition + Interactions

- Interactions within chunks
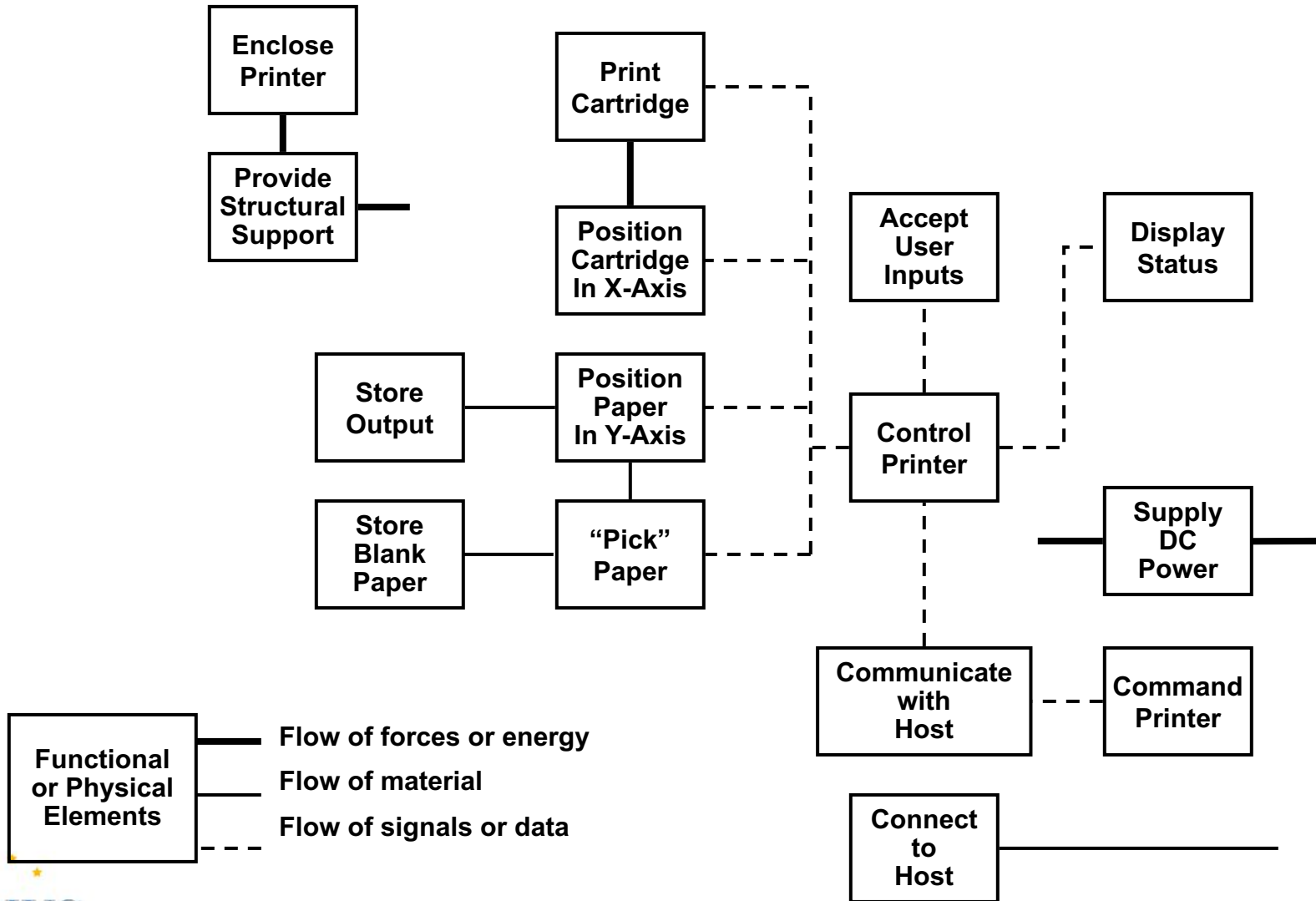
- Interactions across chunks

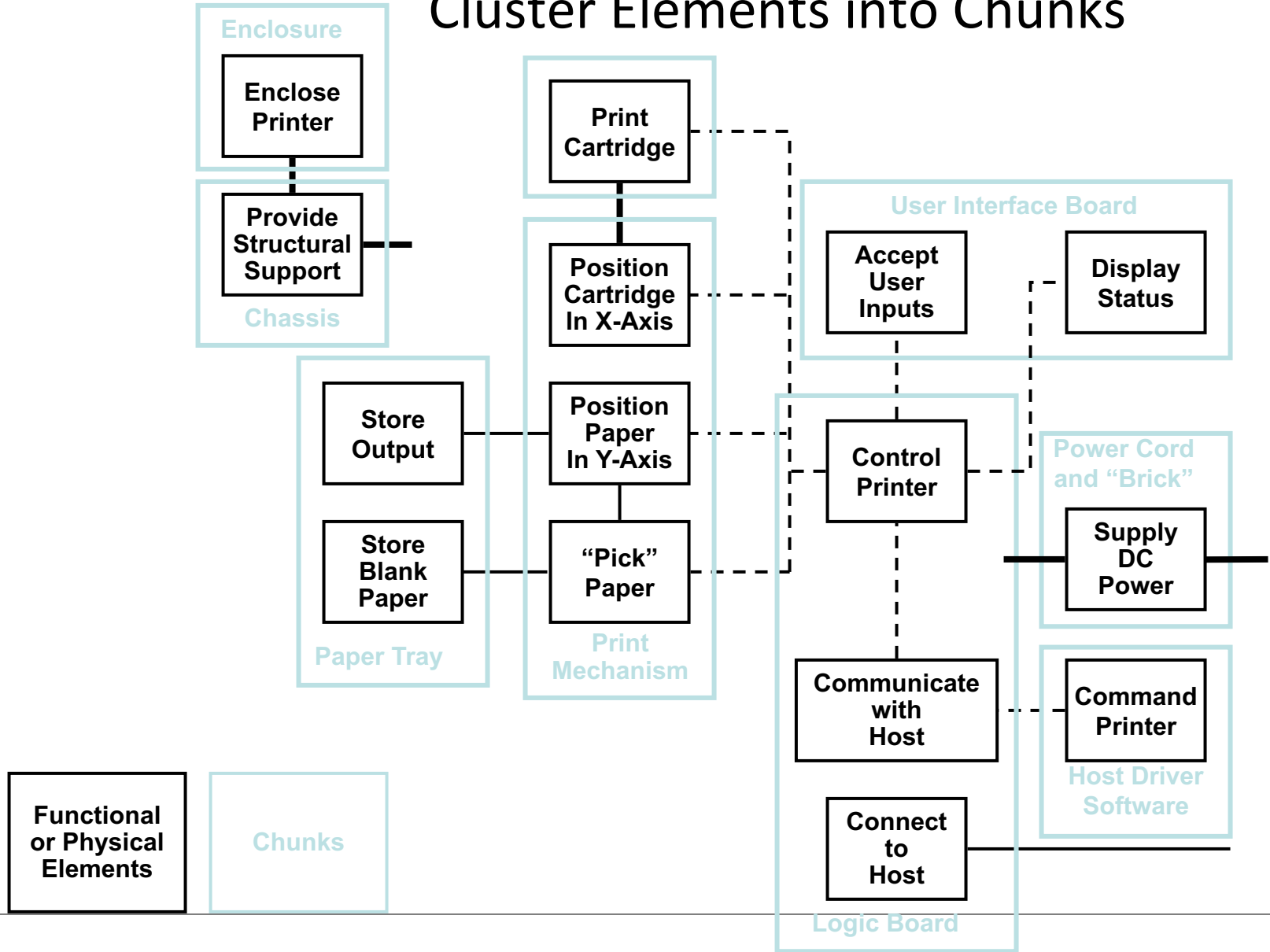# Product Architecture Example:
Hewlett-Packard DeskJet Printer

Establishing the Architecture

To establish a modular architecture, create a schematic of the product, and cluster the elements of the schematic to achieve the types of product variety desired.
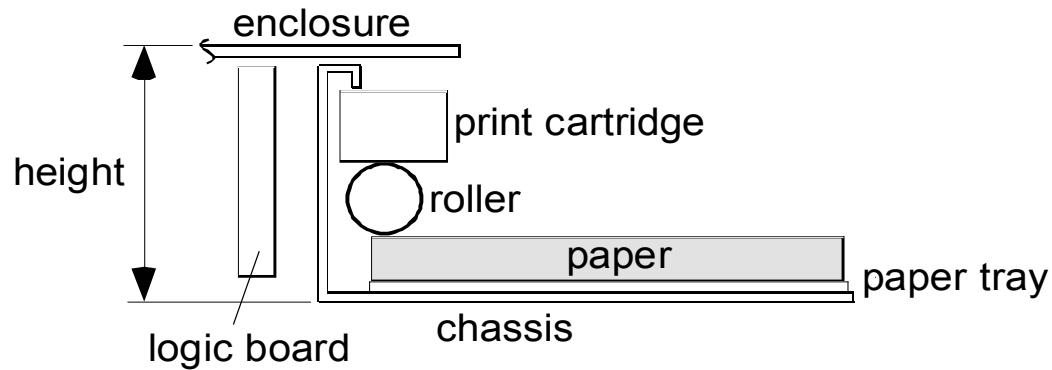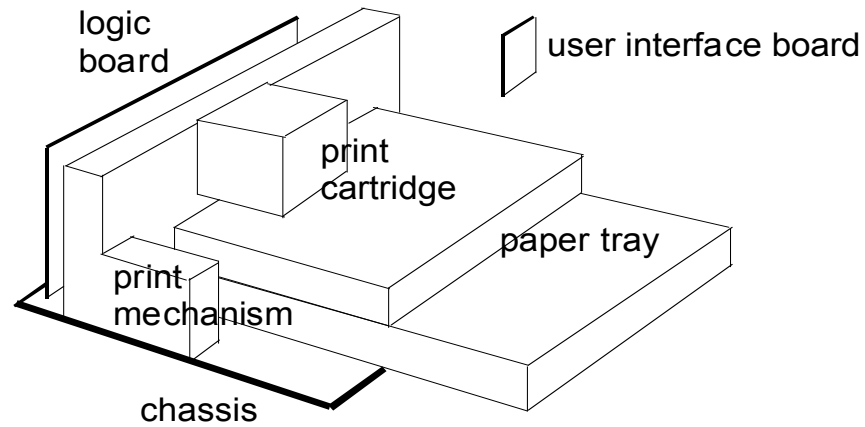
DeskJet Printer Schematic

Enclose Printer

Provide Structural Support

Print Cartridge

Position Cartridge In X-Axis

Accept User Inputs

Display Status

Store Output

Position Paper In Y-Axis

Control Printer

Store Blank Paper

"Pick" Paper

Supply DC Power

Communicate with Host

Command Printer

Functional or Physical Elements

Flow of forces or energy

Flow of material

Flow of signals or data

Connect to Host

Cluster Elements into Chunks

Enclosure

Enclose Printer

Provide Structural Support

Chassis

Print Cartridge

Position Cartridge In X-Axis

Store Output

Position Paper In Y-Axis

Store Blank Paper

"Pick" Paper

Paper Tray

Print Mechanism

User Interface Board

Accept User Inputs

Display Status

Control Printer

Power Cord and "Brick"

Supply DC Power

Communicate with Host

Command Printer

Host Driver Software

Connect to Host

Logic Board

Functional or Physical Elements

Chunks

Geometric Layout

logic board

user interface board

print cartridge

paper tray

print mechanism

chassis

enclosure

height

print cartridge

roller

paper

paper tray

logic board

chassis

Incidental Interactions

Enclosure

Styling

Paper Tray

Vibration

Print Mechanism

Thermal Distortion

Logic Board

User Interface Board

Host Driver Software

RF Interference

Thermal Distortion

RF Shielding

Chassis

Power Cord and "Brick"
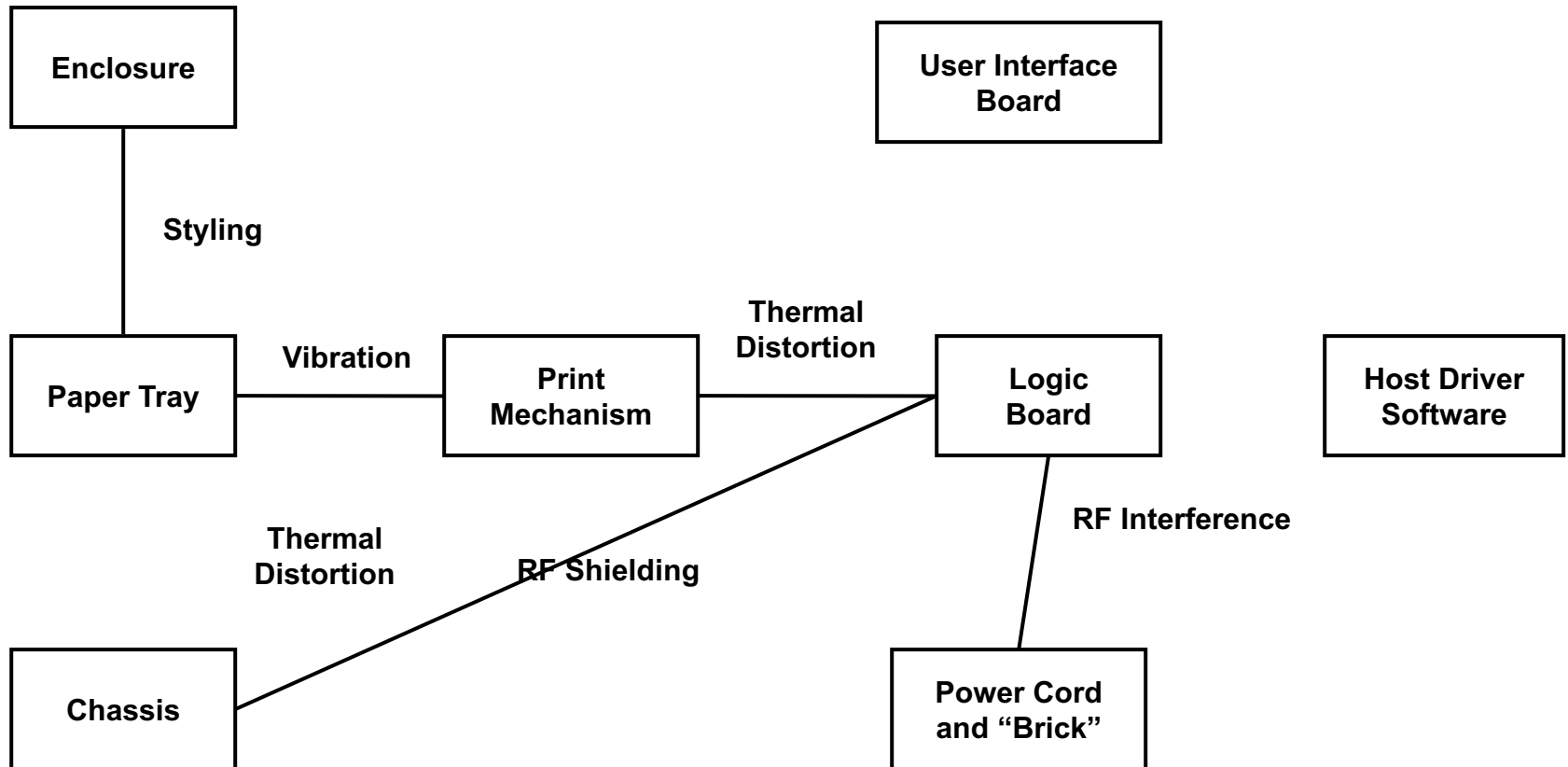
Additional Advantage to Modular Design:
HP products are designed to be recycled.
Recycling design features include:

- Modular design to allow components to be removed, upgraded or replaced
- Eliminating glues and adhesives, for example, by using snap-in features
- Marking plastic parts weighing more than 25g according t ISO 11469 international standards, to speed up materials identification during recycling
- Reducing the number and types of materials used
- Using single plastic polymers
- Using molded-in colors and finishes instead of paint, coatings or plating
- Relying on modular designs for ease of disassembly of dissimilar recyclable materials

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Planning a Modular Product Line: Commonality Table

Chunks	Number of Types	Family	Student	SOHO (small office, home office)
Print cartridge	2	"Manet" Cartridge	"Picasso" Cartridge	"Picasso" Cartridge
Print Mechanism	2	"Aurora" Series	Narrow "Aurora" series	"Aurora" series
Paper tray	2	Front-in Front-out	Front-in Front-out	Tall Front-in Front-out
Logic board	2	"Next gen" board with parallel port	"Next gen" board	"Next gen" board
Enclosure	3	Home style	Youth style	"Soft office" style
Driver software	5	Version A-PC Version A-Mac	Version B-PC Version B-Mac	Version C

Differentiation versus Commonality

Trade off product variety and production complexity

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Fundamental Decisions

- Integral vs. modular architecture?

- What type of modularity?

- How to assign functions to chunks?

- How to assign chunks to teams?

- Which chunks to outsource?

System Team Assignment
Based on Product Architecture
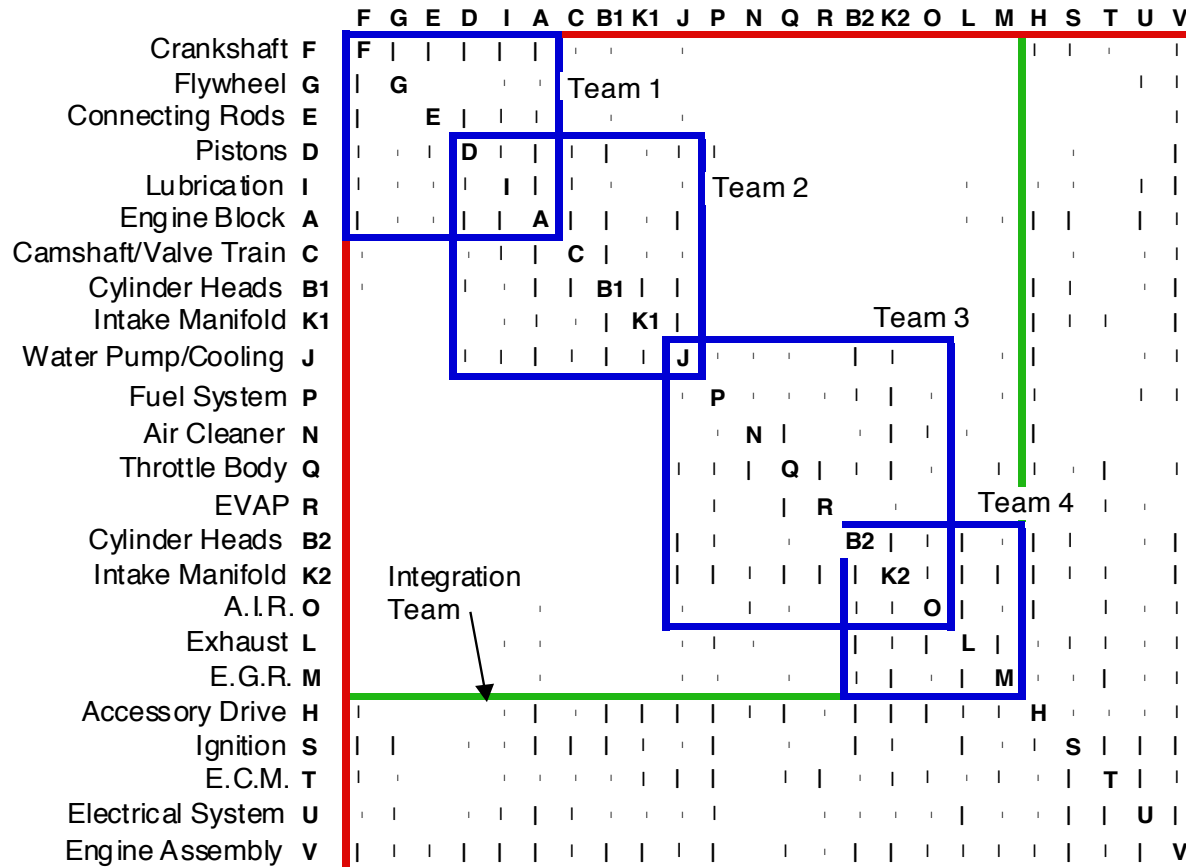
Practical Concerns

- Planning is essential to achieve the desired variety and product change capability.

- Coordination is difficult, particularly across teams, companies, or great distances.

- Special attention must be paid to handle complex interactions between chunks (system engineering methods).

Product Architecture: Conclusions

- Architecture choices define the sub-systems and modules of the product platform or family.

- Architecture determines:
    - ease of production variety
    - feasibility of customer modification
    - system-level production costs

- Key Concepts:
    - modular vs. integral architecture
    - clustering into chunks
    - planning product families

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Power Bricks are annoying to most consumers.
Why are they viewed as a good example of modular design?
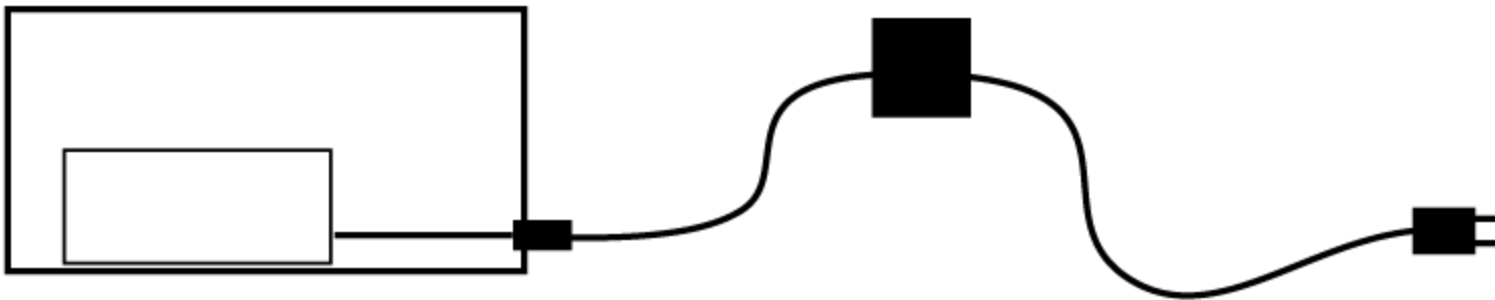
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Product Structure

- Make to order (Dell Computers)

- Make to stock (Roaster Pans)

- Delayed Differentiation (Washing Machines)

Design Conflict: Low Cost vs. Large Variety

- **Integral Design**
  - Focused mission/manufacturing
  - Example – conventional screwdriver

- **Modular Design**
  - Flexible mission/manufacturing
  - Example – bit holder and driver bits

Point of Product Differentiation

The point in the manufacturing process where a product can only be made into a specific stock keeping unit (SKU)

Delayed Point of Product Differentiation

- The point in the manufacturing process where an item is limited to use for a single specific product is called the "Point of Product Differentiation"

- Delaying the point of product differentiation is called "Late Point Product Differentiation"

Delayed differentiation or **Postponement** is a concept in supply chain management where the manufacturing process starts by making a generic or family product that is later differentiated into a specific end-product. This is a widely used method, especially in industries with high demand uncertainty, and can be effectively used to address the final demand even if forecasts cannot be improved.

An example would be Benetton and their knitted sweaters that are intially all white, and then dyed into different colored only when the seasons customer color preference/demand is know. It is usually necessary to redesign the products specifically for delayed differentiation, and resequence to modify the order of product manufacturing steps.

From Wikipedia

Advantages of Late Point Product Differentiation

- Reduced inventories
- More easily respond to demand variation

Late Point Differentiation Examples

- Paint where pigment is added at the store
- Benetton sweaters
- HP printers

Grand Prize, a trip which will be donated in your name to...

Send us your favorite recipe using **Mama Mary's® Pizza Crusts** along with a picture of your pizza and your family. (Photos not mandatory for entry.)

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Contest runs from January 1 thru December 31

CONTEST CATEGORIES:

YOUR MAMA'S FAVORITE PIZZA™
(THE PIZZA THAT MADE YOU SMILE AS A KID!)

MAIL YOUR RECIPE TO: RECIPE CONTEST, SPARTAN FOODS OF AMERICA, INC., P.O. BOX 1171, SPARTANBURG, SC 29304 OR VISIT US AT WWW.MAMAMARYS.COM. You'll be entered in the contest and added to our mailing list!

Submitted by: DENNIS DEEL
(GRAND PRIZE WINNER of the PIZZA CREATIONS RECIPE CONTEST™)
KEY WEST TROPICAL CHEESE BURGER PIZZA

Yields 8 slices
1 Mama Mary's 12" Gourmet Pizza Crust
Olive oil to mist the rim of the crust
1/2 teaspoon Italian Seasoning
1 tablespoon Nellie & Joe's Famous Key West Lime Juice
1 cup diced fresh mango
1 cup red bell pepper, chopped
1/4 cup cucumber, peeled, seeded and chopped
1/4 cup shallots, chopped
1/2 cup cilantro, rough chopped
1/4 teaspoon Tabasco Sauce
Kosher salt
4 strips of peppered bacon, crumbled
3/4 pound extra lean ground beef
Freshly ground black pepper to taste
3/4 cup pizza sauce
9 sandwich size slices of Kraft 2% Sharp Cheddar Cheese

Preheat oven to 450° F. Line a vented pizza pan or large baking sheet with parchment baking paper that has been trimmed so edges will not hang over the pan or touch the oven wall, place crust on the pan. Mist the crust and the rim with olive oil. Evenly sprinkle the Italian seasoning on the crust, but not on the edges. Set aside.

In a non-reactive bowl, (glass or plastic), combine lime juice, mango, bell pepper, cucumber, shallots, cilantro and Tabasco Sauce. Stir until well combined, season with salt, to taste. Cover and let marinate at room temperature while cooking ground beef and bacon.

Cook bacon over medium high heat until crispy. Remove to paper towels to drain. Wipe out skillet. In the same skillet add ground beef and freshly ground black pepper, to taste. Brown until meat is no longer pink, transfer meat to paper towels to drain.

Spread the pizza sauce over the crust, but not on the rim. Evenly distribute the hamburger over the sauce, top with crumbled bacon. Take 8 cheese squares and slightly overhang one corner of each square on the rim of crust, squares will over lap each other. Place the remaining cheese square in the middle of the pizza. Drain the marinated mixture, and with a slotted spoon evenly distribute marinated topping over the cheese slices. Reduce oven to 425° F.

Keeping pizza on the pan, bake for 8-10 minutes. To crisp the crust, remove from the parchment-lined pan and place directly on the oven rack for 2-3 minutes. Cool 5 minutes before slicing.

Preheat oven to 450°F.
Remove pizza crust from package.

1. Lightly brush crust with olive oil.

Top crust with desired ingredients.

2.

3. Lower oven temperature to 425°F. Bake on oven rack or cookie sheet (middle position) for 7 1/2 to 10 min.

Hint: For a crisper crust, broil until desired appearance is achieved.

Submitted by: ERIN RENOUF MYLROIE
(GRAND PRIZE WINNER of the PIZZA CREATIONS RECIPE CONTEST™)
CHICKEN PESTO CLUB PIZZA

Yields 8 slices
1 Mama Mary's 12" Gourmet Pizza Crust
Olive oil to mist the rim of the crust
1 tablespoon sesame seeds
1/2 cup prepared pesto
1/2 cup mayonnaise
1 tablespoon Dijon mustard
2 Roma tomatoes, peeled and sliced
1 1/2 cups cooked chicken, shredded
8 slices of bacon, cooked, drained and crumbled
1 cup Mozzarella Cheese, shredded
3/4 cup Parmesan Cheese, shredded
10 basil leaves, rolled and thinly sliced
tablespoons pine nuts, toasted

Preheat oven to 450°F. Line a vented pizza pan with parchment baking paper that has been trimmed so edges will not hang over the pan or touch the oven wall. Mist the crust and rim with olive oil, sprinkle with sesame seeds.

Combine pesto, mayonnaise and Dijon mustard, mix very well. Spread over the pizza. Top with tomatoes, chicken, bacon and cheeses.

Reduce oven temperature to 425°F.

Keeping pizza on the pan, bake for 10 minutes. To crisp the crust remove from the lined pan and place directly on the oven rack for 3 additional minutes.

Remove from oven. Top pizza with basil leaves and pine nuts.

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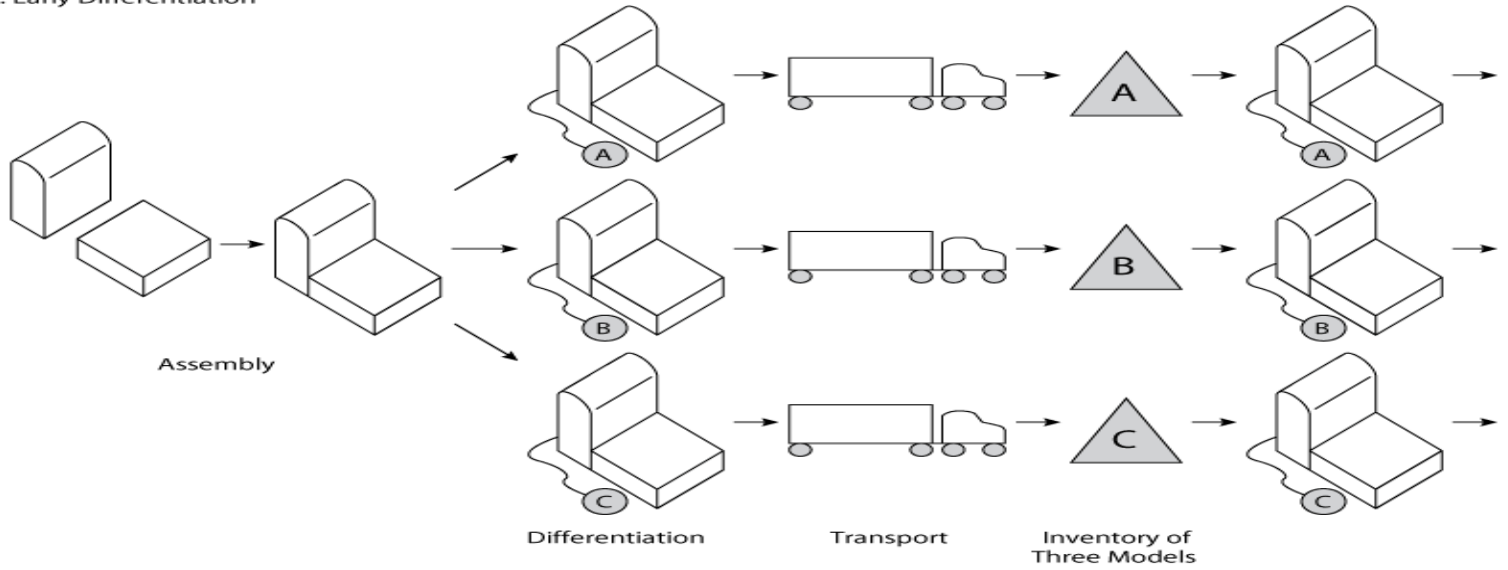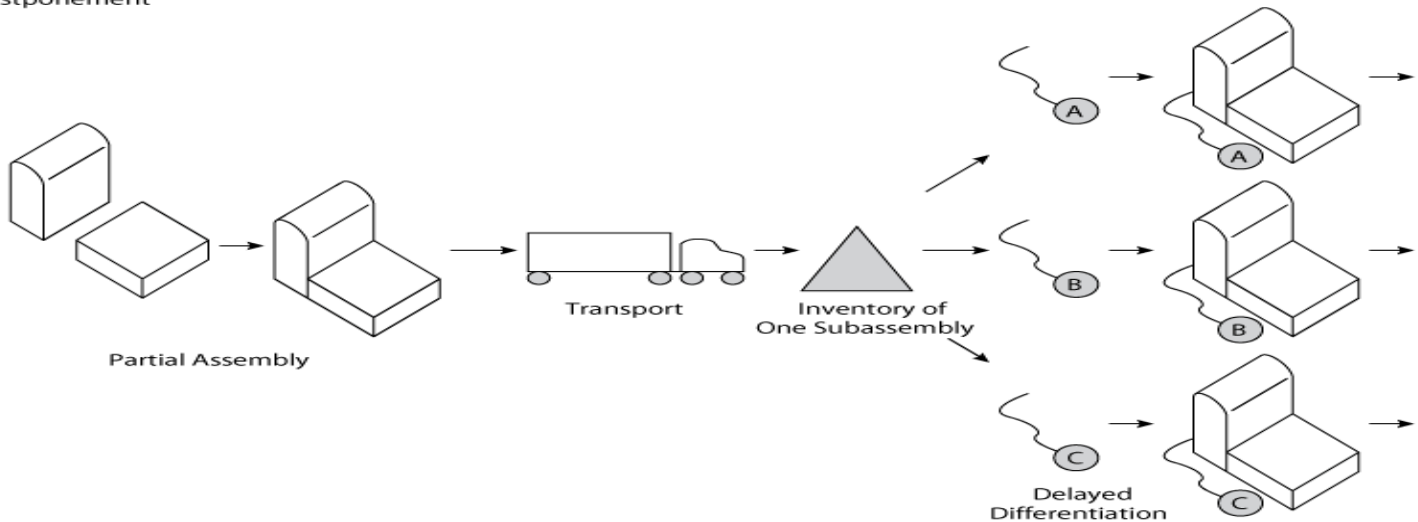
SFA

Modular Design allows for Late Point Differentiation

Benefits of Late Differentiation

- Easier to control
- Faster reaction to customer requirement
- Lower inventory costs
- Fewer interfaces

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Scenario A: Early Differentiation

Assembly — Differentiation — Transport — Inventory of Three Models

Scenario B: Postponement

Partial Assembly — Transport — Inventory of One Subassembly — Delayed Differentiation

From *Product Design and Development* by Karl Ulrich and Steven Eppinger (McGraw-Hill/Irwin)

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Assembly Sequence

Late Differentiation

Differentiated Product

Feature Options
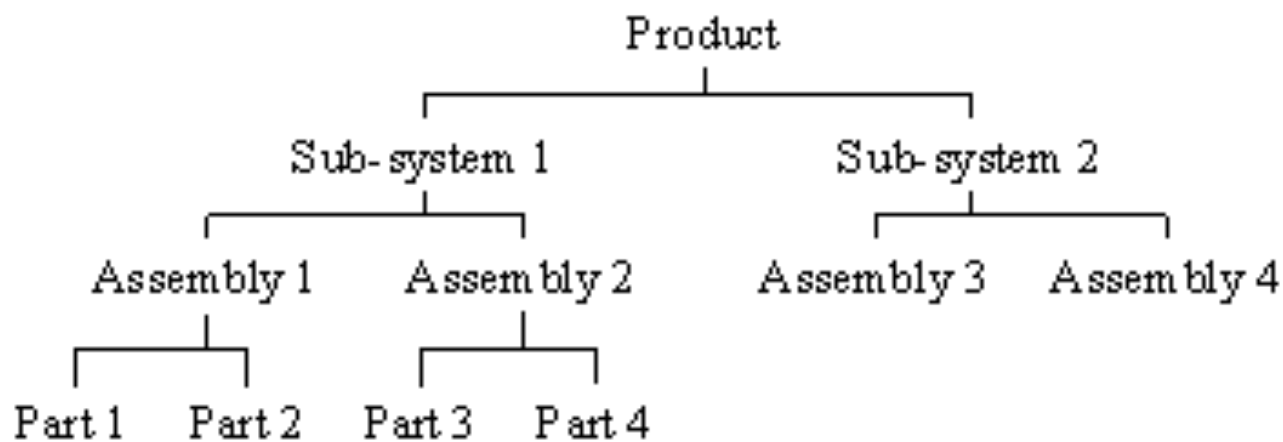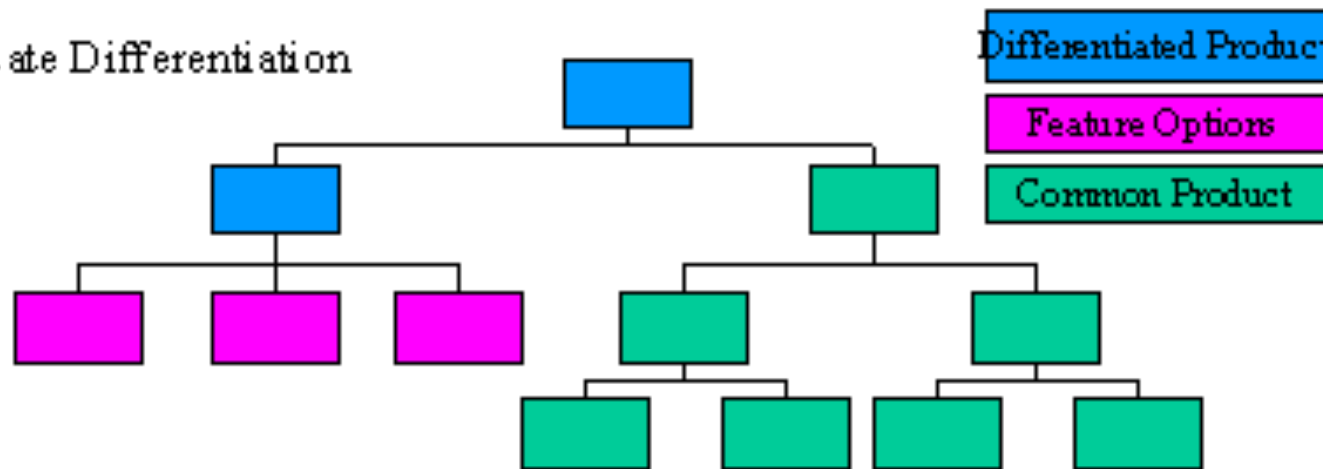
Common Product
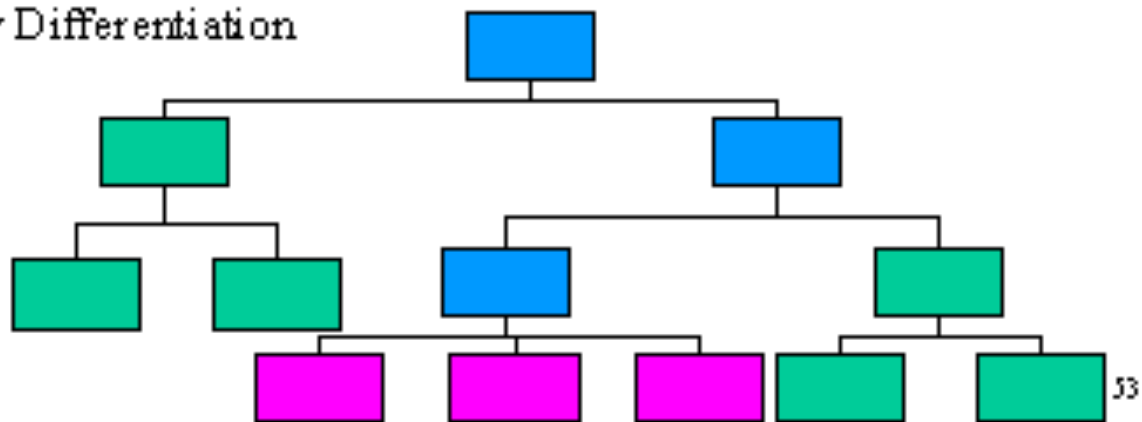
Early Differentiation

53

Late Point Differentiation Principles

- The differentiating elements of the product must be concentrated in one or a few chunks

- The product and production process must be designed so that the differentiating chunk(s) can be added to the product near the end of the supply chain.

Platform Planning

The process of deciding what should be shared across products and what should be unique across products?

For example:

- How many driveshafts should you have for a Ford F150?

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Platform Planning

- Attempts to resolve the tension between

    1. Differentiating the product for various customers

    2. Taking advantage of the economic benefits of using common components

- Product architecture will determine what trade-offs are available... if no good options are available, see if the options can be improved by changing the product architecture