Chapter 9: Product Architecture

Product Design and Development

Fourth Edition

by Karl T. Ulrich and Steven D. Eppinger

Product Design and Development

Karl T. Ulrich and Steven D. Eppinger

2nd edition, Irwin McGraw-Hill, 2000.

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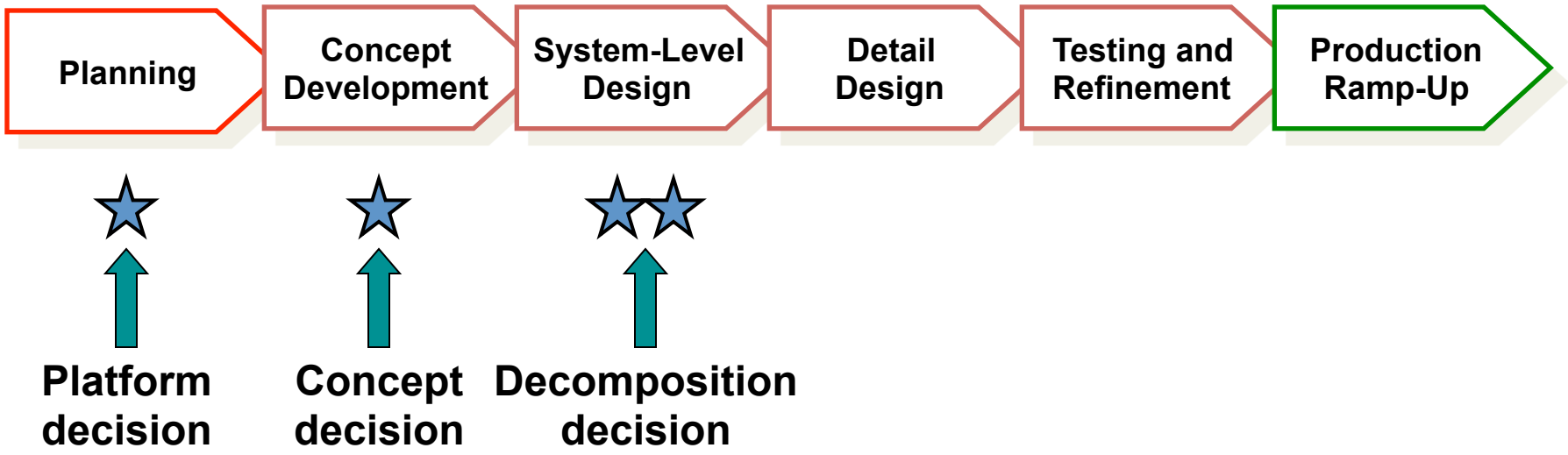
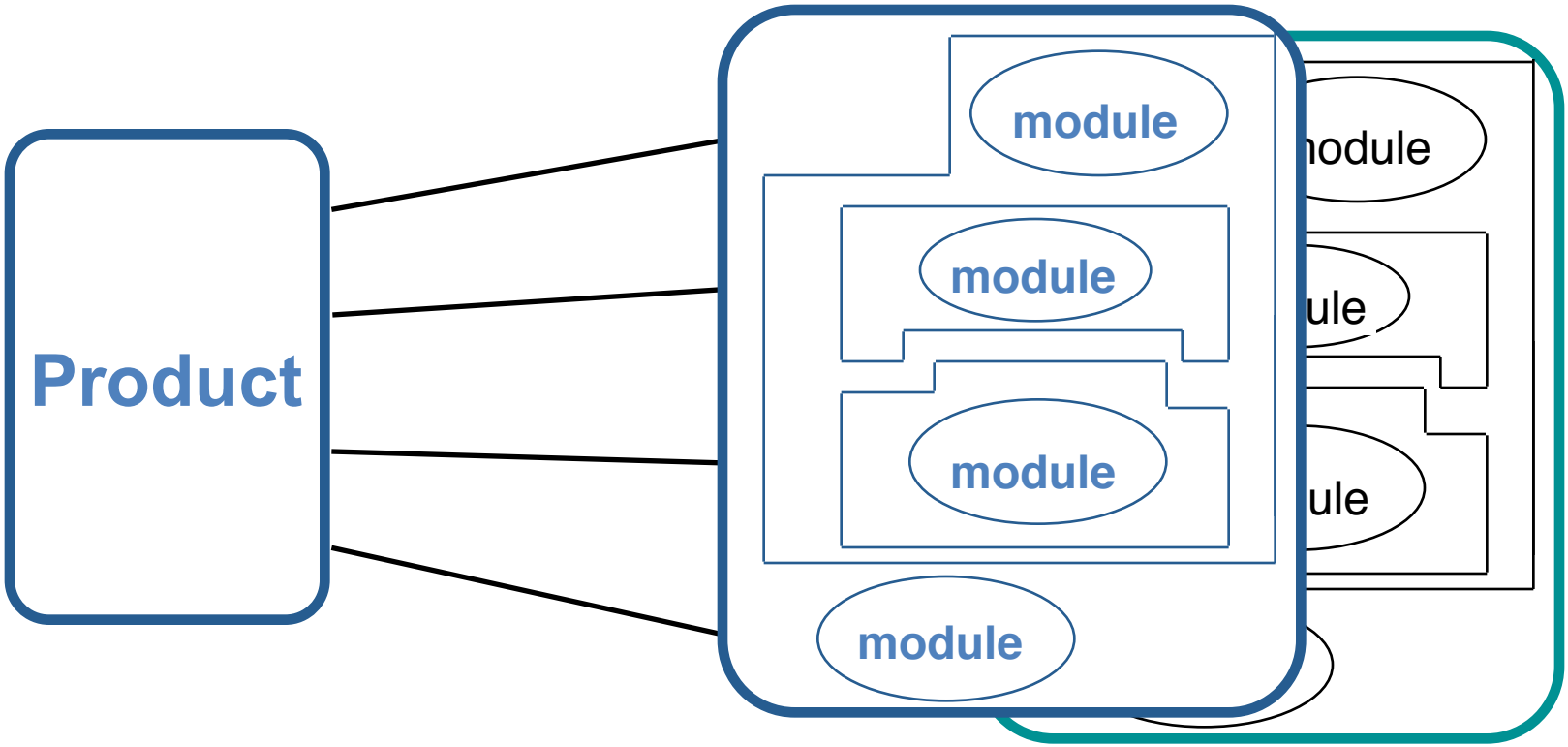
Product Development Process



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

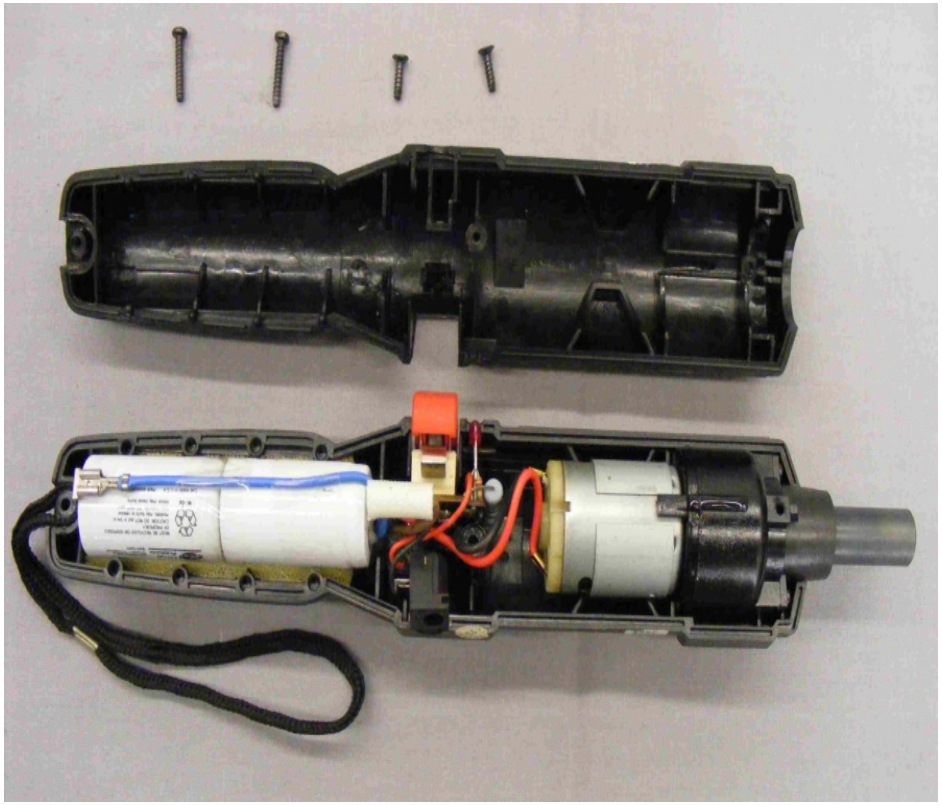
Modular Design Displays the Following Properties:

- 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.

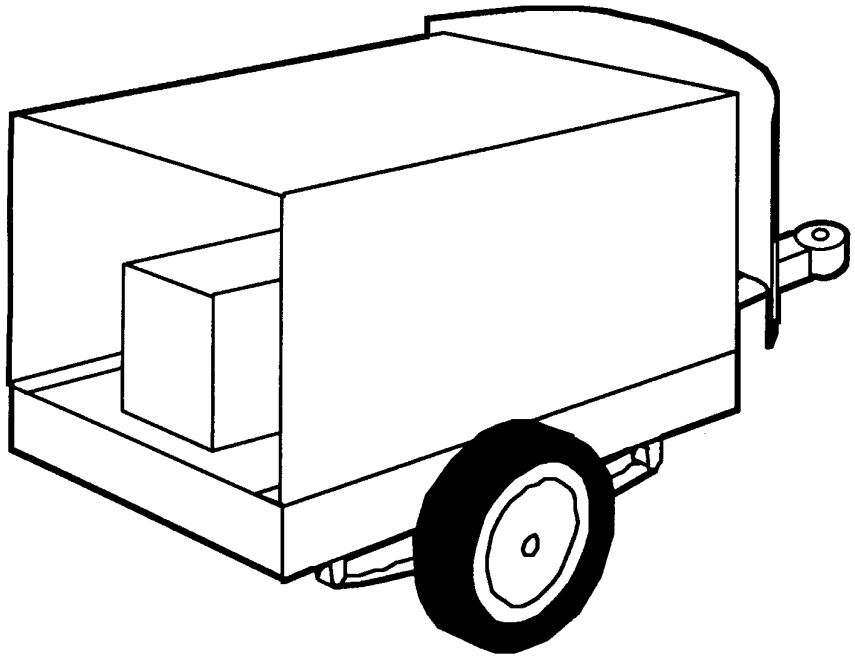
Modular or Integral?



Examples

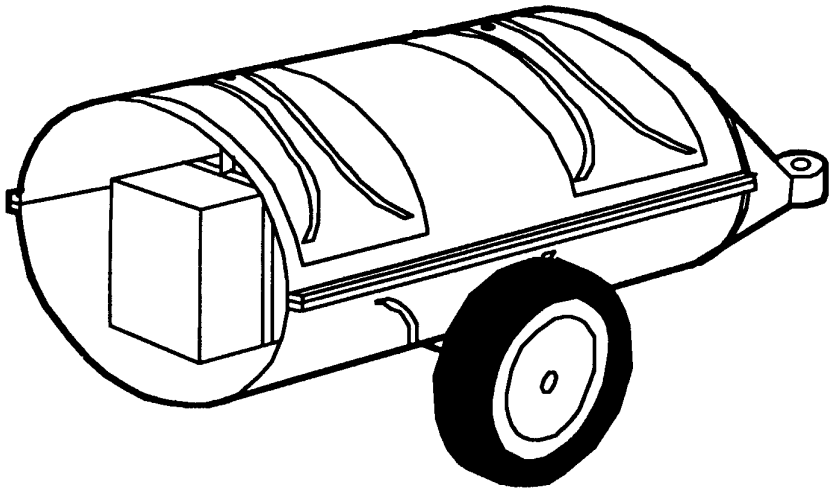
- Video Games
  - Modular: gaming systems (e.g. GameCube)
  - Integrated: stand-alone arcade games
- Power Supplies
  - Modular: power bricks
  - Integrated: on-board power converter

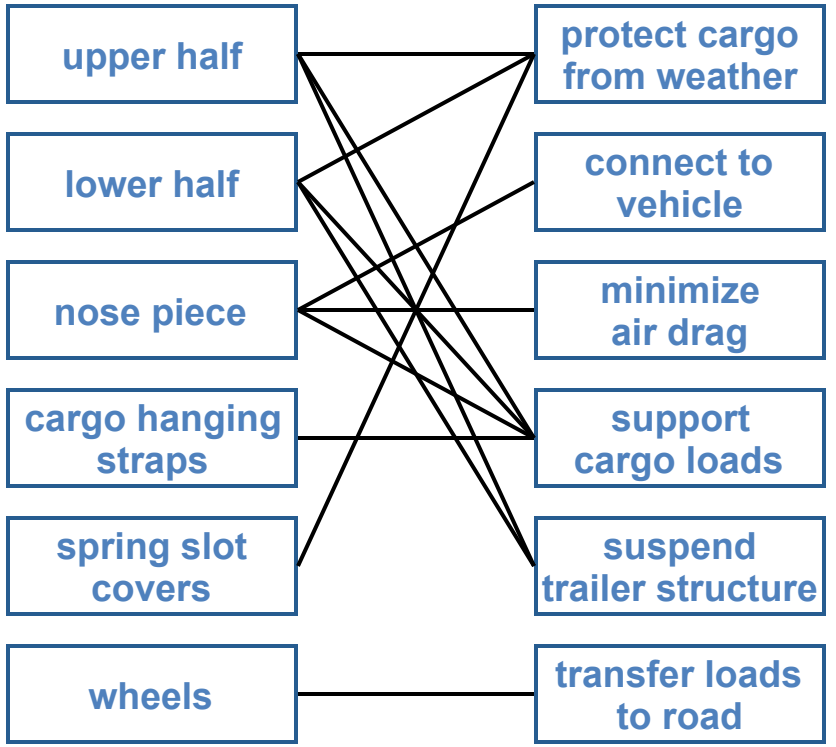
Trailer Example: Modular Architecture



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





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

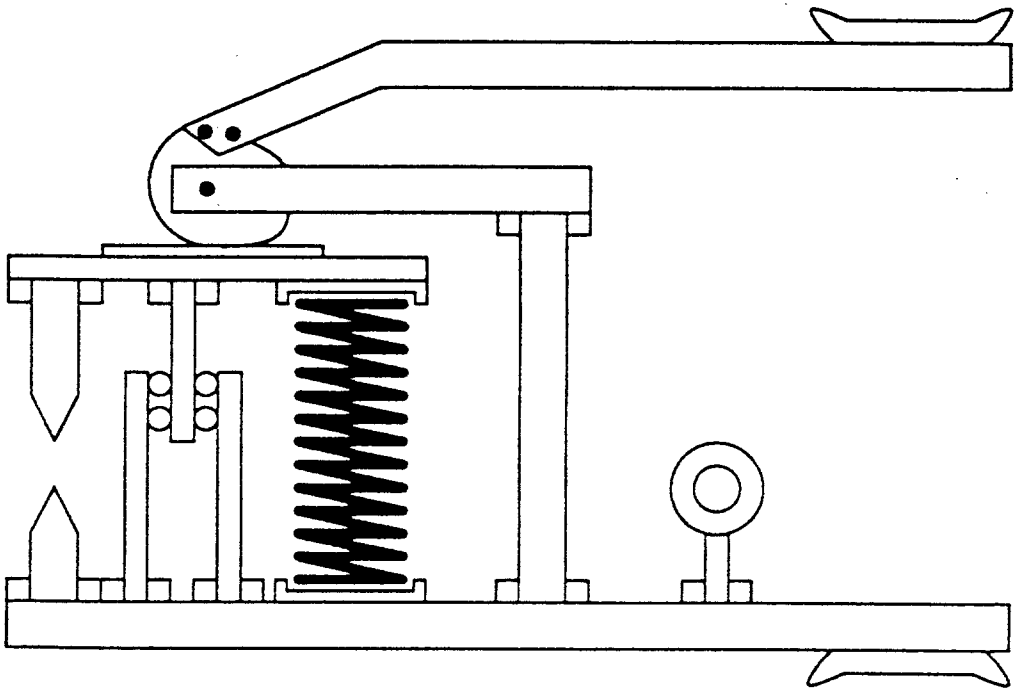
Integral

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

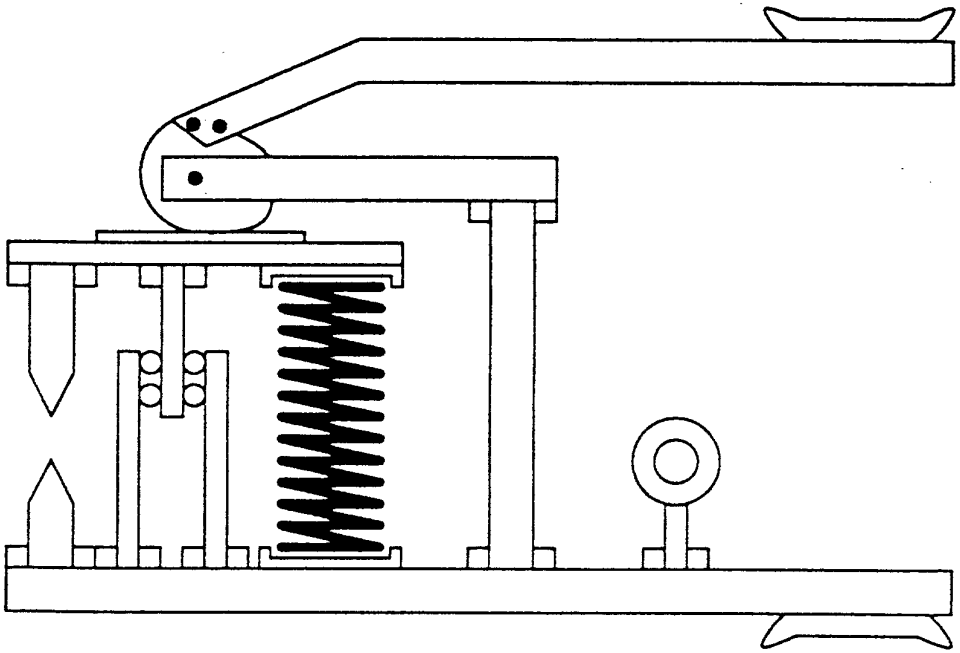
Modular

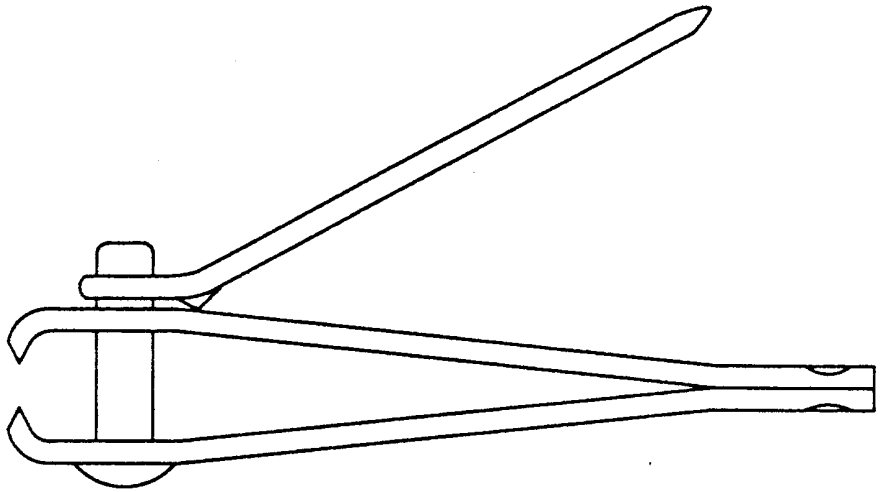
- Changeability
- Decoupled design teams
- Reduced performance
- Requires flexible manufacturing
- Cheaper at low volumes

What is this?



Nail Clippers?



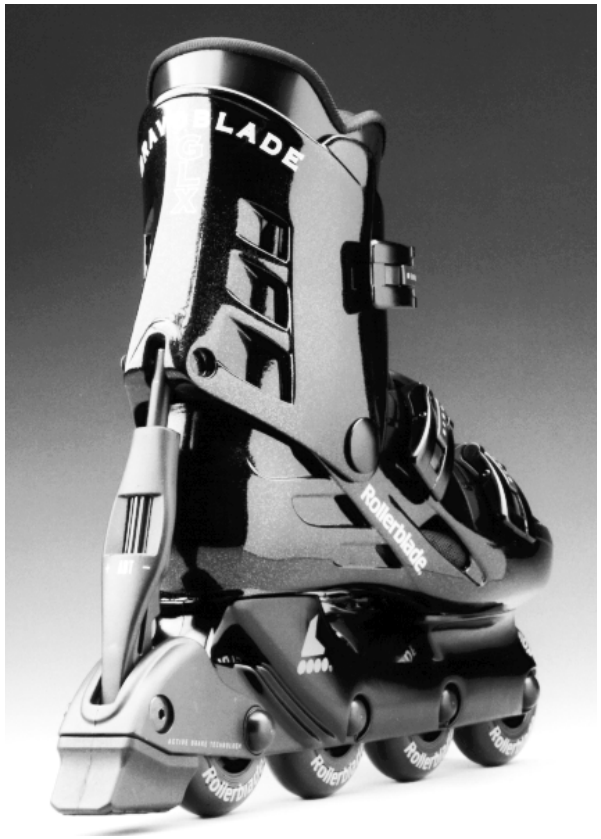


Modular or Integral Architecture?

Motorola StarTAC
Cellular Phone

Apple
iBook

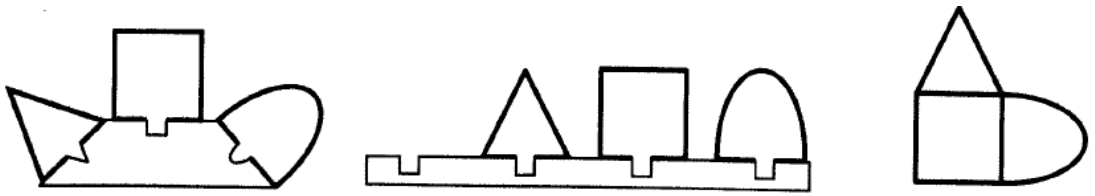
Ford
Explorer



Rollerblade
In-Line Skates

Types of Modularity

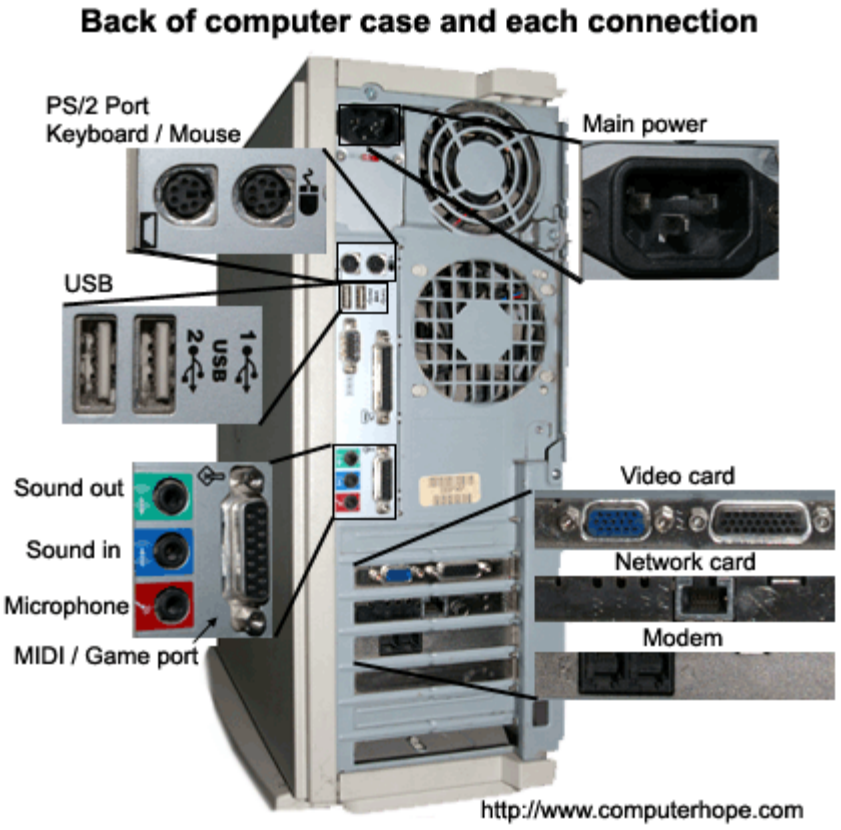
- Slot-Modular Architecture
  - unique interfaces for attachment to a base element (e.g. pacemaker leads)
- Bus-Modular Architecture
  - common interfaces for attachment to a base element (e.g. USB connectors on a computer)
- Sectional-Modular Architecture
  - Common interfaces between elements without a base element (e.g. legos & piping)



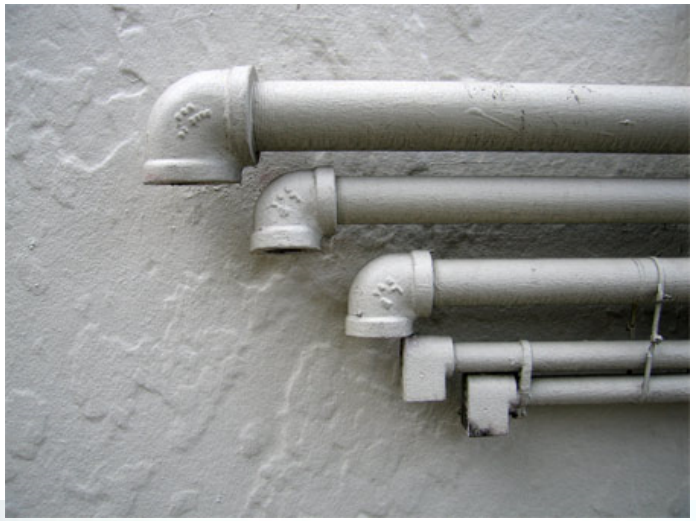
Slot-modular architecture

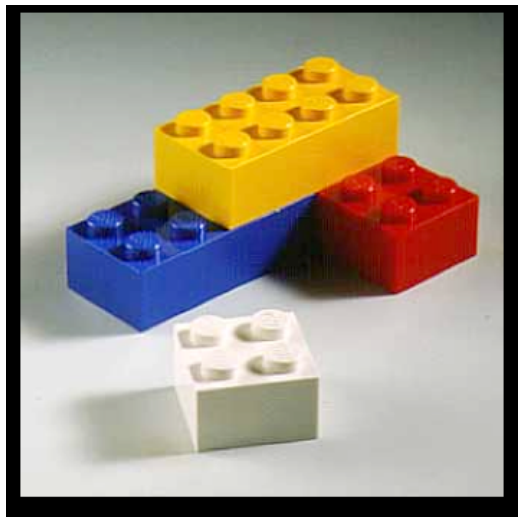
Bus-modular architecture

Sectional-modular architecture



Bus?
Slot?
Sectional?





(COURTESY BRICKARTIST.C

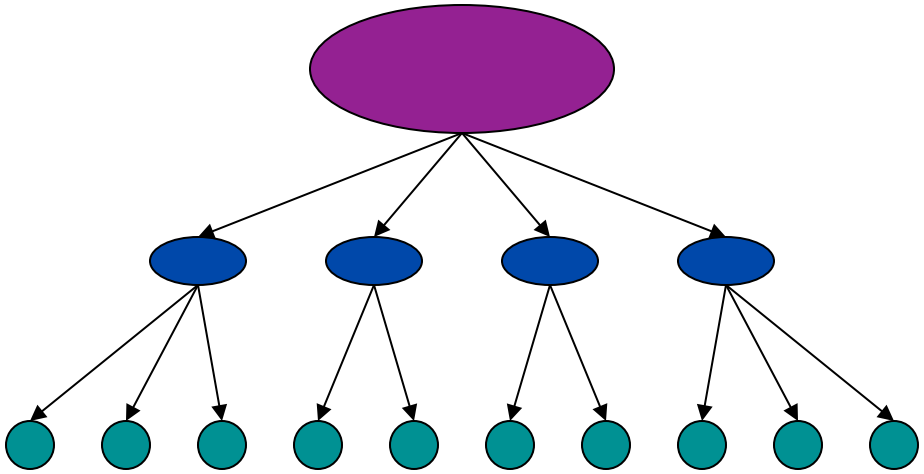
Choosing the Product Architecture

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:

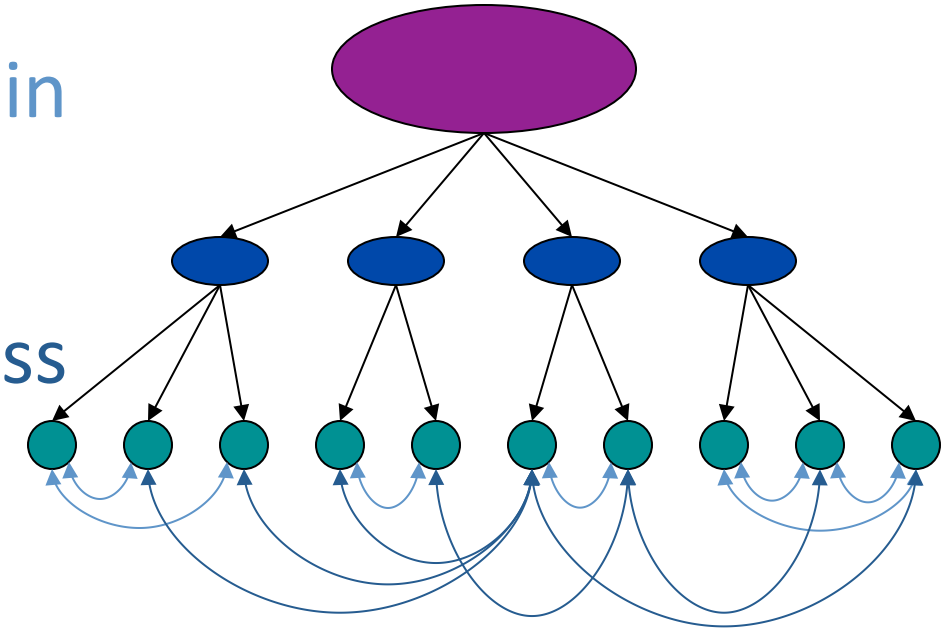
- system
- sub-system
- component



Product Architecture = Decomposition + Interactions

⟺ Interactions within chunks

⟺ Interactions across chunks

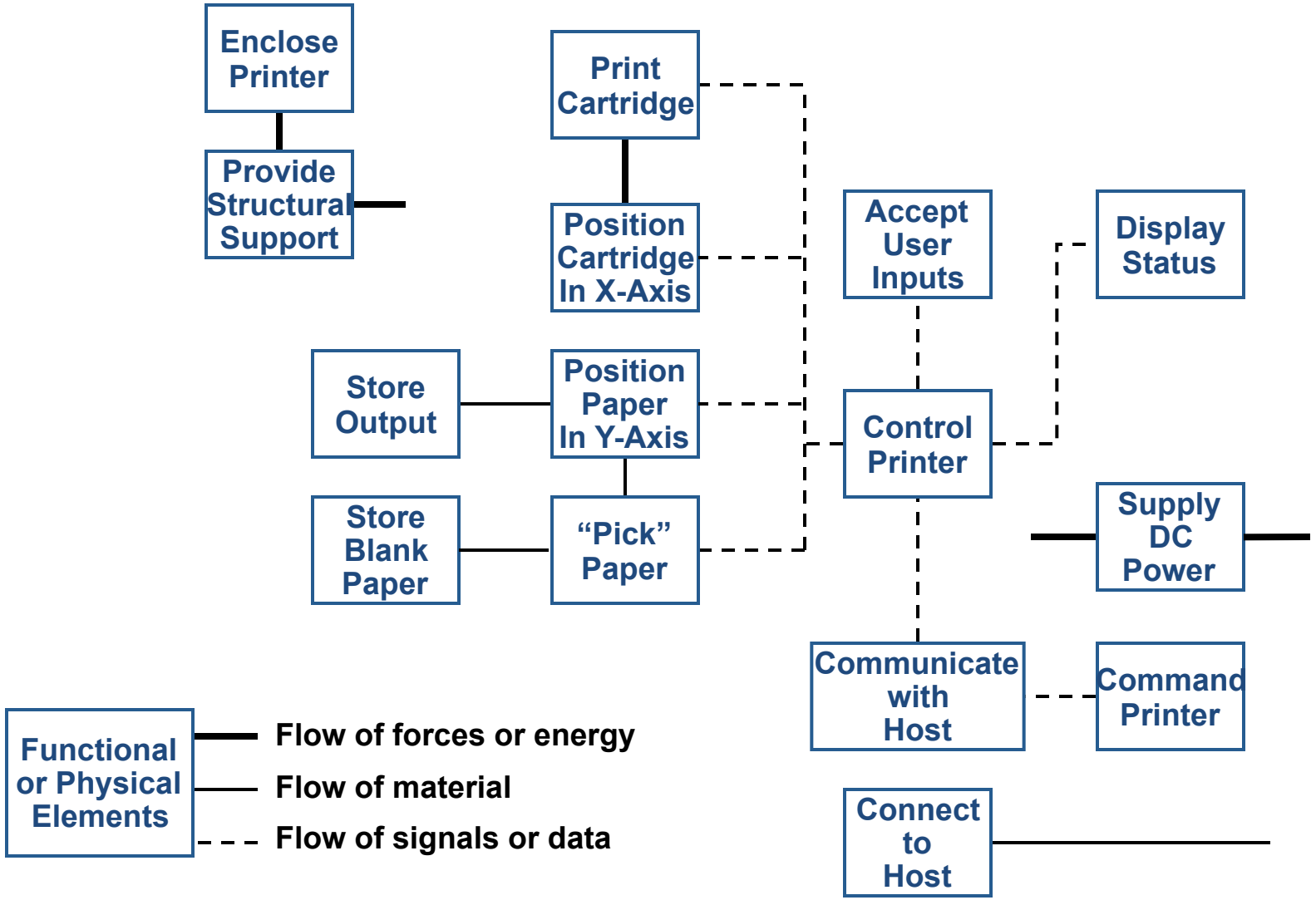


Product Architecture Example: Hewlett-Packard DeskJet Printer

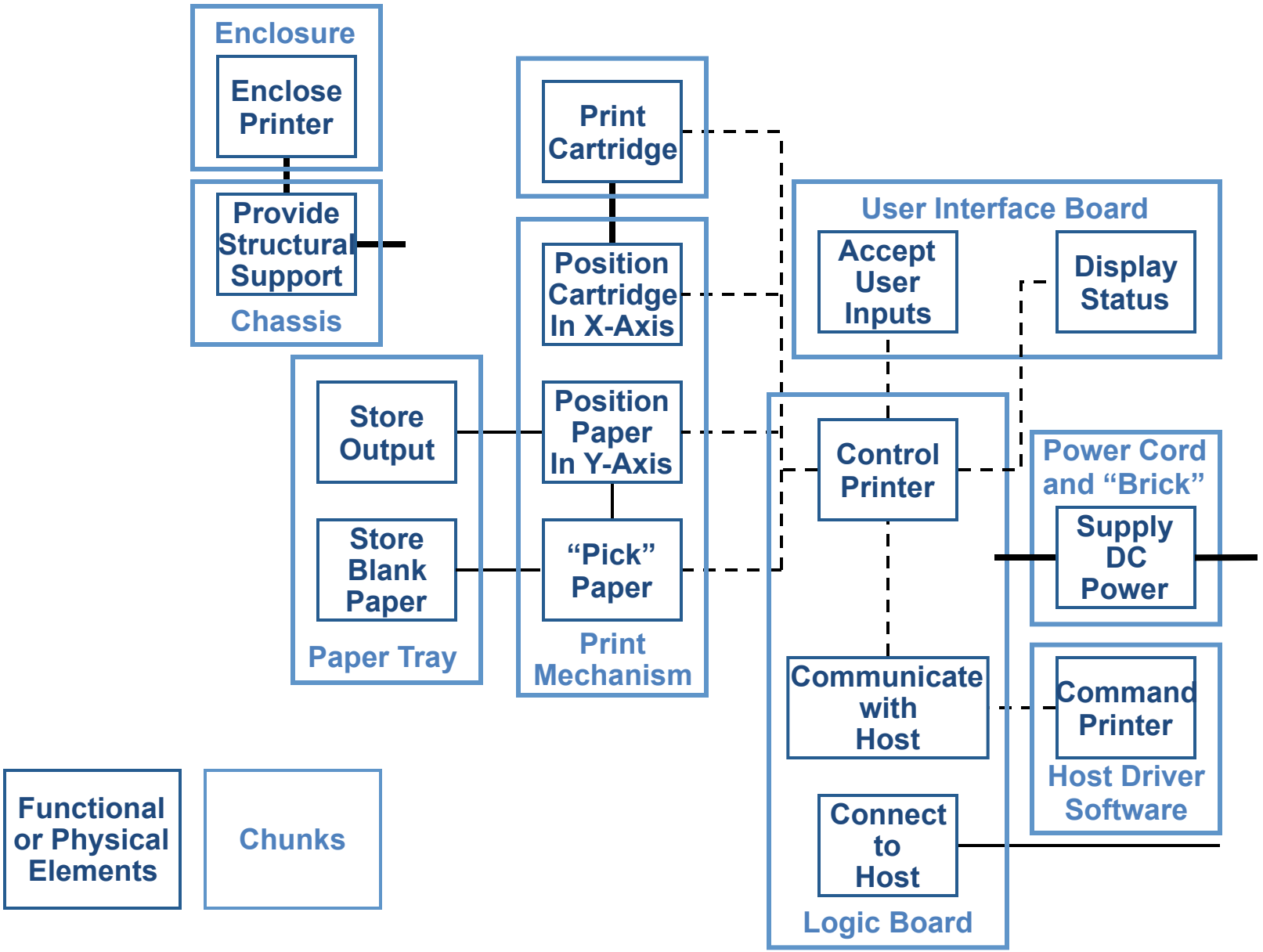
Establishing the Architecture

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.

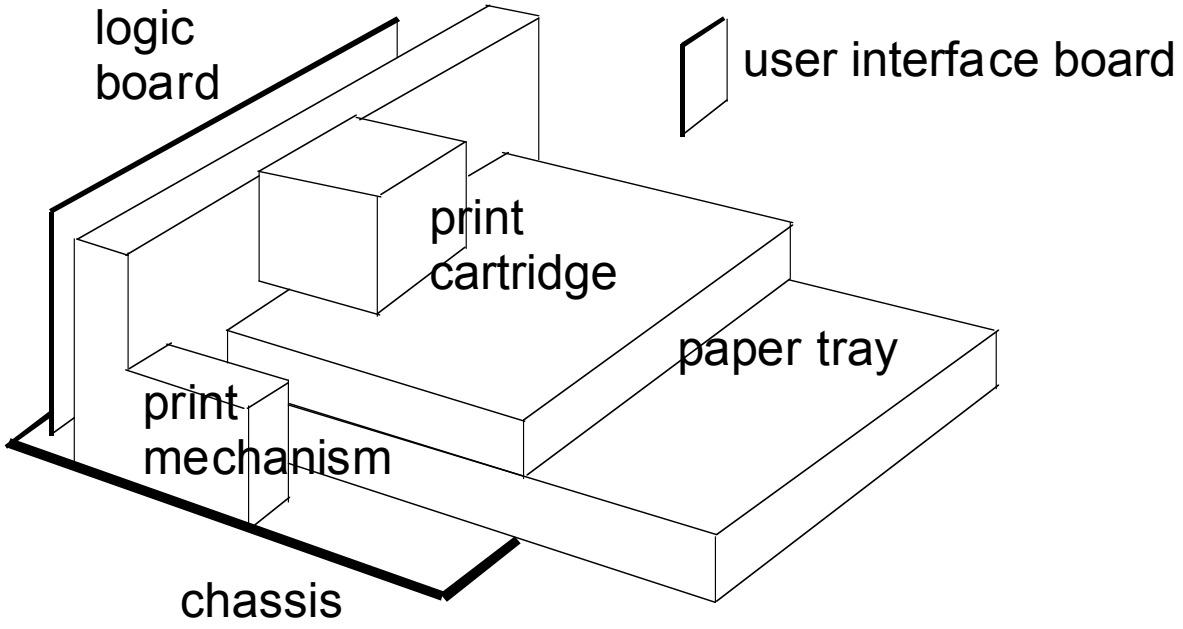
DeskJet Printer Schematic

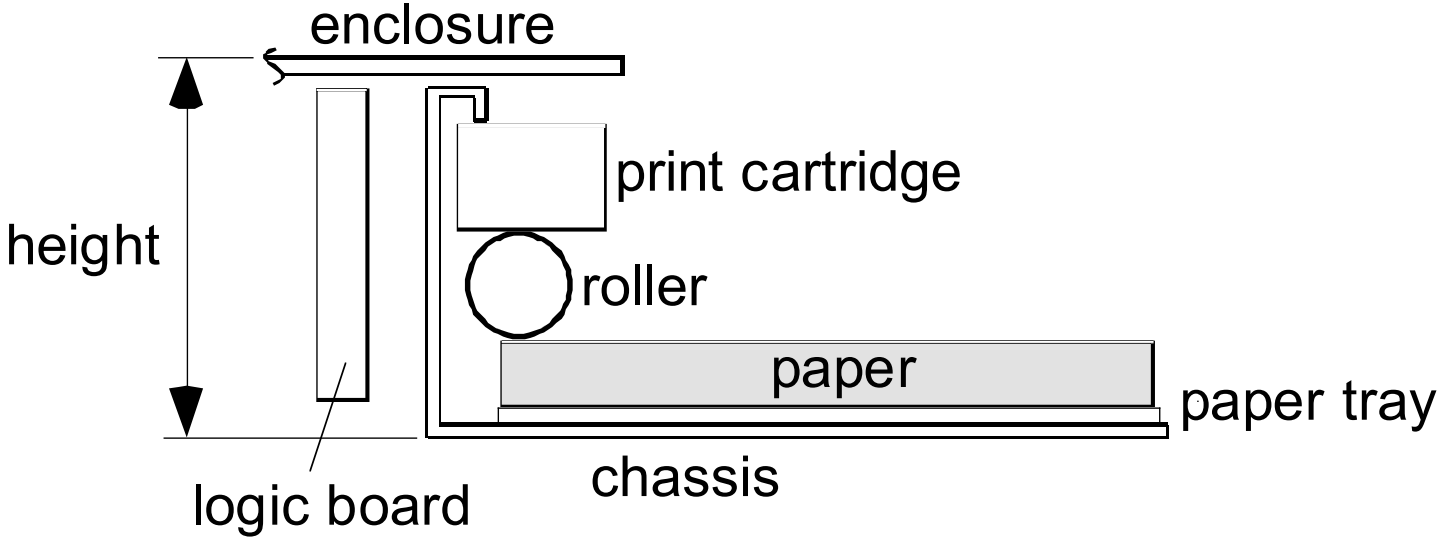


Cluster Elements into Chunks

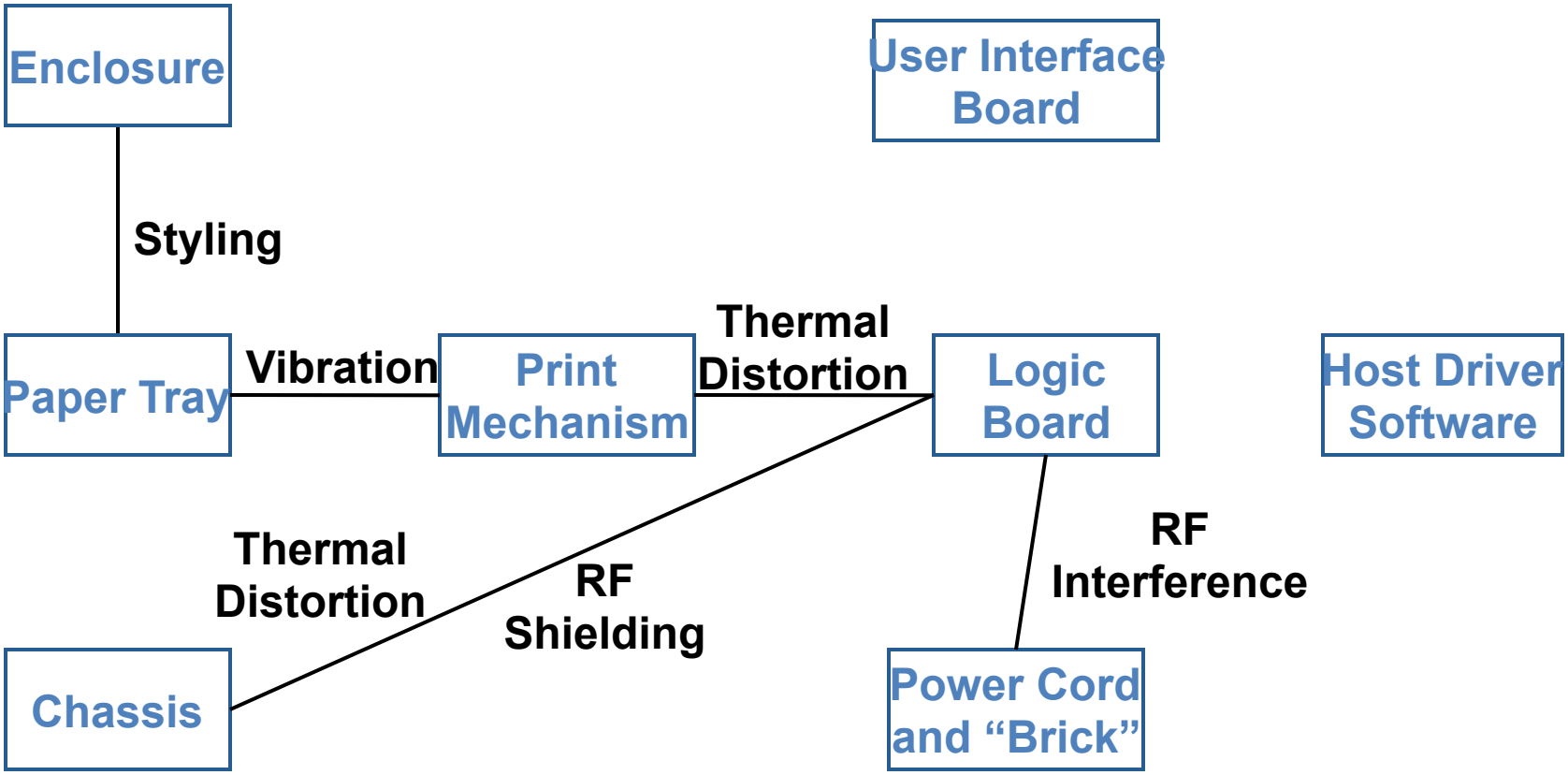


Geometric Layout





Incidental Interactions



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

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

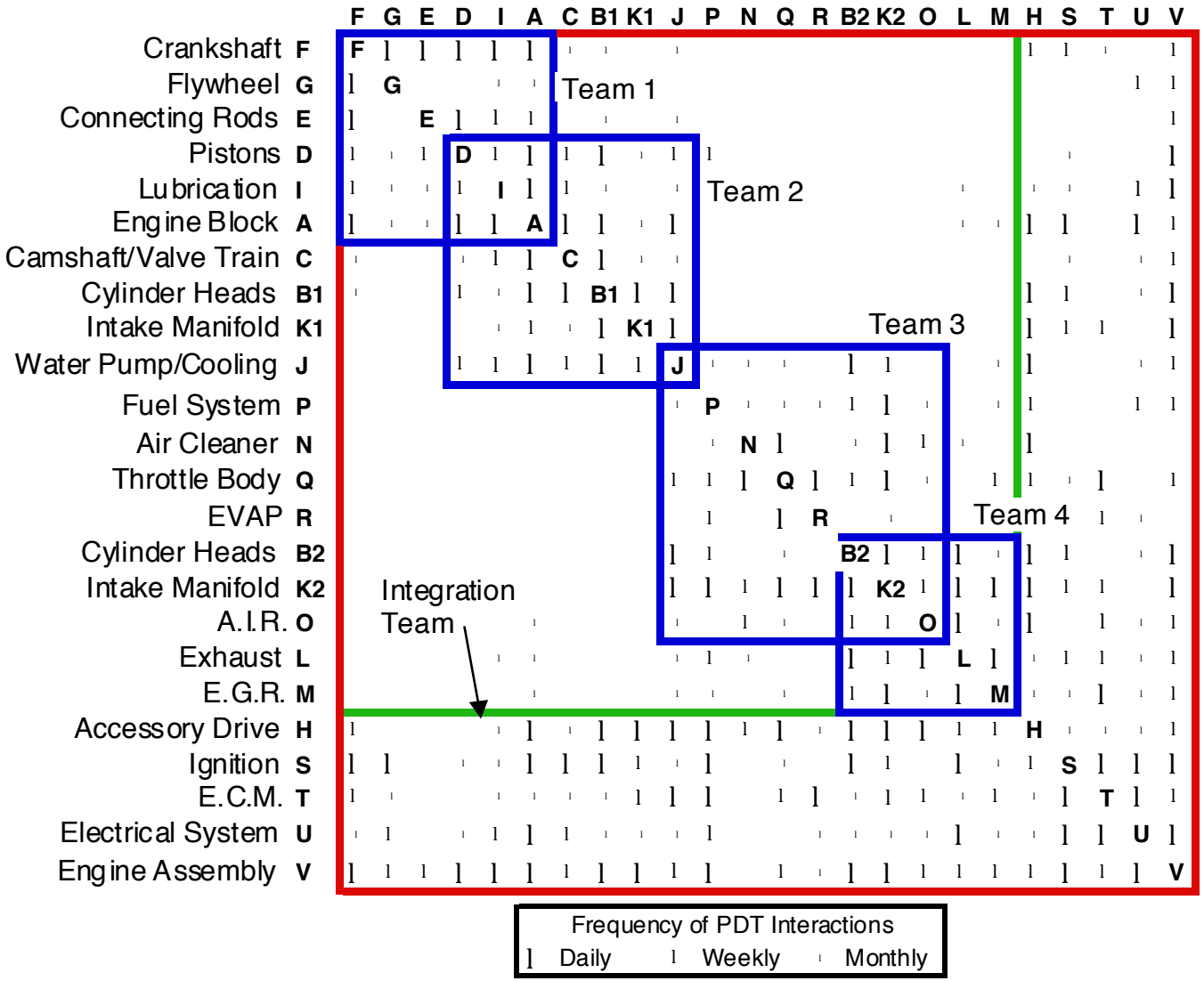
Differentiation versus Commonality

Trade off product variety and production complexity

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



From “Innovation at the Speed of Information”, S. Eppinger, *HBR*, January 2001.

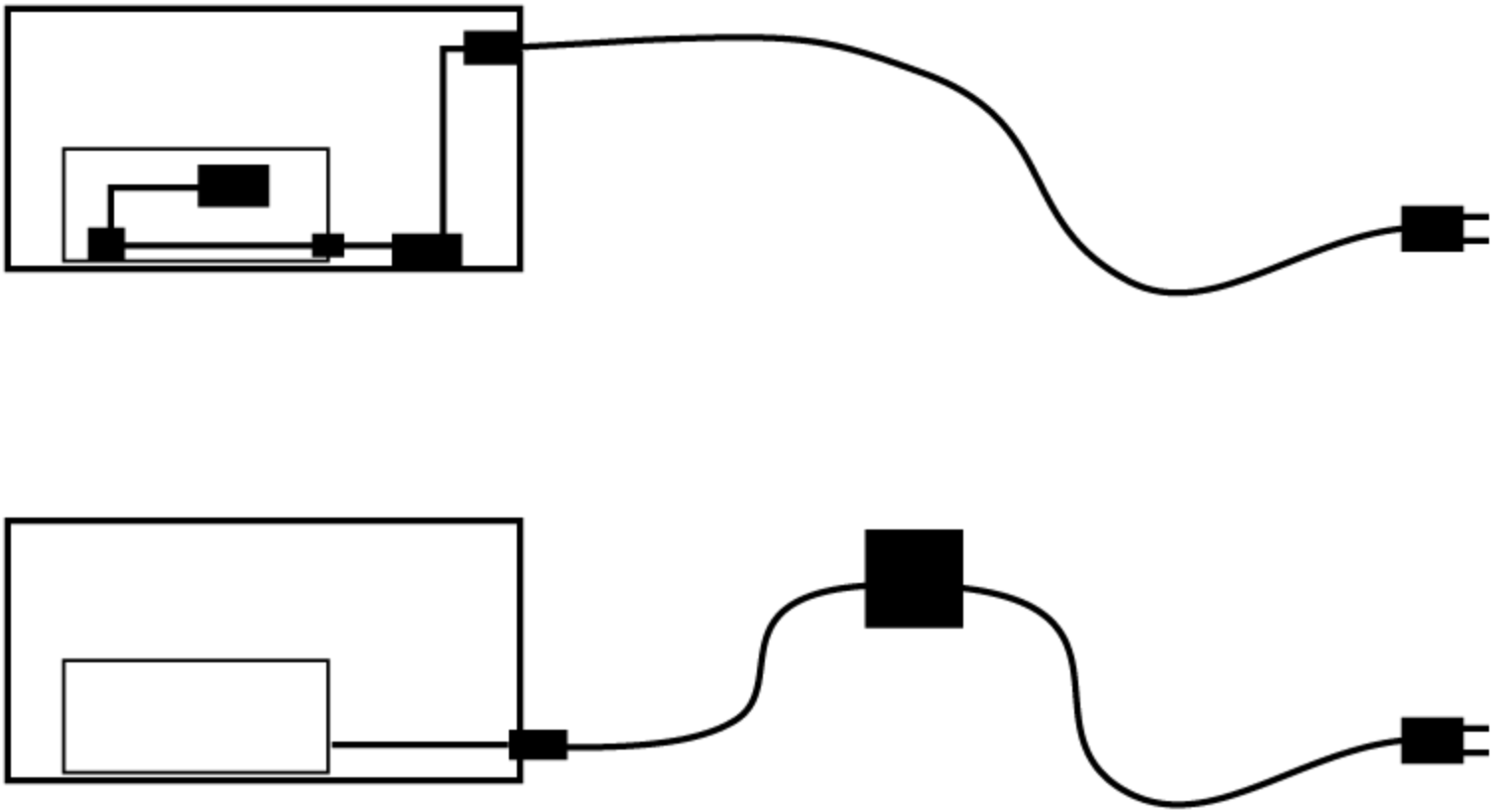
Practical Concerns

- 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

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



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

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

back

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

FAVORITE PIZZA™ Pizza Creations RECIPE CONTEST

Grand Prize, a trip [illegible] which will be donated in your name to [illegible]

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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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
1/4 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 over 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.


2 Top crust with desired ingredients.


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
2 tablespoons pine nuts, toasted

Preheat oven to 450°F. Line a vented pizza pan with parchment baking paper that has t trimmed so edges will not hang over the pan or touch the oven wall. Mist the crust an 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.

TO ORDER OUR COOKBOOK, *The Best Pizza Recipes in America,* **FEATURING MAMA MARY'S® GOURMET PIZZA CRUSTS, WRITE TO US AT THE ADDRESS ABOVE OR VISIT OUR WEBSITE AT: WWW.MAMAMARYS.COM**

Nutrition Facts — 12" Pizza Crusts

Serving Size 1/6 Pizza Crust (57g/2oz.)
Servings per package 12

Amount Per Serving	
Calories 190	Calories from Fat 50
	% Daily Value*
Total Fat 6g	9%
Saturated Fat 1g	5%
Trans Fat 0g	0%
Cholesterol 0mg	8%
Sodium 190mg	9%
Total Carbohydrate 28g	5%
Dietary Fiber 1g	
Sugars 1g	
Protein 6g	

Vitamin A 0% • Vitamin C 0%
Calcium 8% • Iron 0%

*Percent daily values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2400mg	2400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

INGREDIENTS: Enriched flour (wheat flour, malted barley flour, niacin, ferrous sulfate, thiamine mononitrate, riboflavin, folic acid), water, soybean oil, contains less than 2% of the following: yeast, calcium propionate & potassium sorbate (preservatives), vinegar, salt, dried honey, calcium carbonate, cornstarch, mineral oil, tricalcium phosphate, l-cysteine, calcium stearate, ascorbic acid added as dough conditioner.
Allergens: contains wheat

Nutrition Facts — 12" Whole Wheat Pizza Crusts

Serving Size 1/4 Pizza Crust (57g/2oz.)
Servings per package 8

Amount Per Serving	
Calories 156	Calories from Fat 47
	% Daily Value*
Total Fat 5g	8%
Saturated Fat 1g	5%
Trans Fat 0g	0%
Cholesterol 0mg	0%
Sodium 240mg	10%
Total Carbohydrate 25g	8%
Dietary Fiber 4g	16%
Sugars .5g	
Protein 5g	

Vitamin A 0% • Vitamin C 0%
Calcium 5% • Iron 8%

*Percent daily values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2400mg	2400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

INGREDIENTS: Whole wheat flour, water, soybean oil, contains less than 2% of each of the following: wheat gluten, salt, yeast, vinegar, dried honey, calcium propionate and potassium sorbate (preservatives), honey, wheat starch, l-cysteine, soy flour, ascorbic acid added as dough conditioner.
Allergens: contains wheat and soy. Manufactured on shared equipment with egg and milk.

Nutrition Facts — 12" Deep Dish Pizza Crust

Serving Size 1/8 Pizza Crust (57g/2oz.)
Servings per package 8

Amount Per Serving	
Calories 190	Calories from Fat 50
	% Daily Value*
Total Fat 6g	9%
Saturated Fat 1g	5%
Trans Fat 0g	0%
Cholesterol 0mg	8%
Sodium 190mg	9%
Total Carbohydrate 28g	5%
Dietary Fiber 1g	
Sugars 1g	
Protein 6g	

Vitamin A 0% • Vitamin C 0%
Calcium 8% • Iron 0%

*Percent daily values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2400mg	2400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

INGREDIENTS: Enriched flour (wheat flour, malted barley flour, niacin, ferrous sulfate, thiamine mononitrate, riboflavin, folic acid), water, soybean oil, contains less than 2% of the following: natural garlic butter flavor, yeast, calcium propionate & potassium sorbate (preservatives), vinegar, salt, dried honey, calcium carbonate, cornstarch, mineral oil, tricalcium phosphate, l-cysteine, calcium stearate, ascorbic acid added as dough conditioner.
Allergens: contains wheat, dairy

Nutrition Facts — 12" Thin & Crispy Pizza Crusts

Serving Size 1/4 Pizza Crust (57g/2oz.)
Servings per package 8

Amount Per Serving	
Calories 190	Calories from Fat 50
	% Daily Value*
Total Fat 6g	9%
Saturated Fat 1g	5%
Trans Fat 0g	0%
Cholesterol 0mg	8%
Sodium 190mg	9%
Total Carbohydrate 28g	5%
Dietary Fiber 1g	
Sugars 1g	
Protein 6g	

Vitamin A 0% • Vitamin C 0%
Calcium 8% • Iron 0%

*Percent daily values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2400mg	2400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

INGREDIENTS: Enriched flour (wheat flour, malted barley flour, niacin, ferrous sulfate, thiamine mononitrate, riboflavin, folic acid), water, soybean oil, contains less than 2% of the following: yeast, calcium propionate & potassium sorbate (preservatives), vinegar, salt, dried honey, calcium carbonate, cornstarch, mineral oil, tricalcium phosphate, l-cysteine, calcium stearate, ascorbic acid added as dough conditioner.
Allergens: contains wheat

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If for any reason you are dissatisfied with our product, clip the date code from the front of the package and return it along with your sales receipt and written comments for a full refund to:

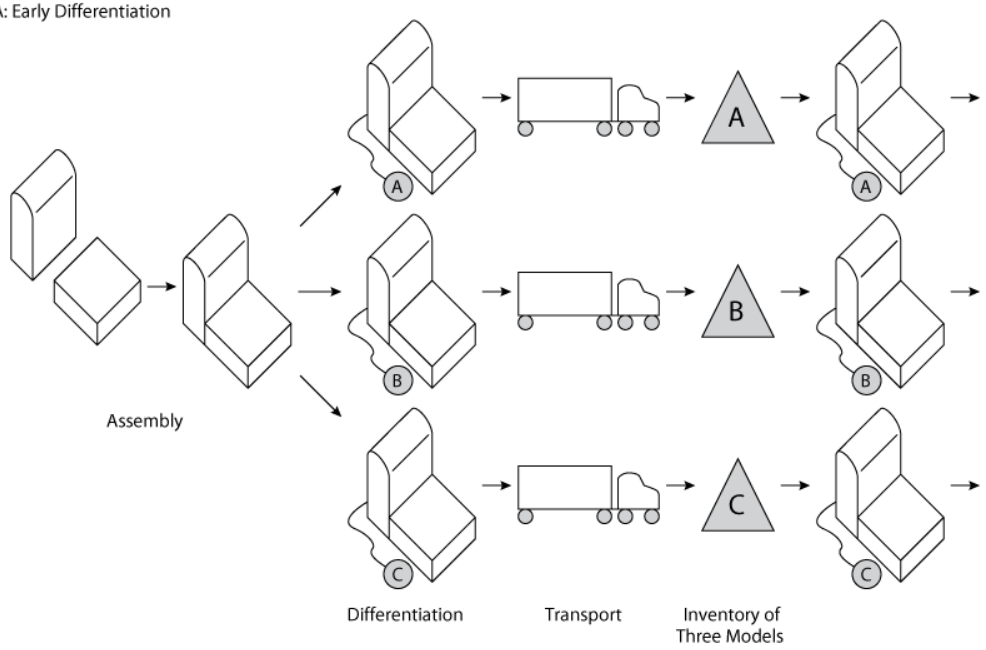
SFA

Modular Design allows for Late Point Differentiation

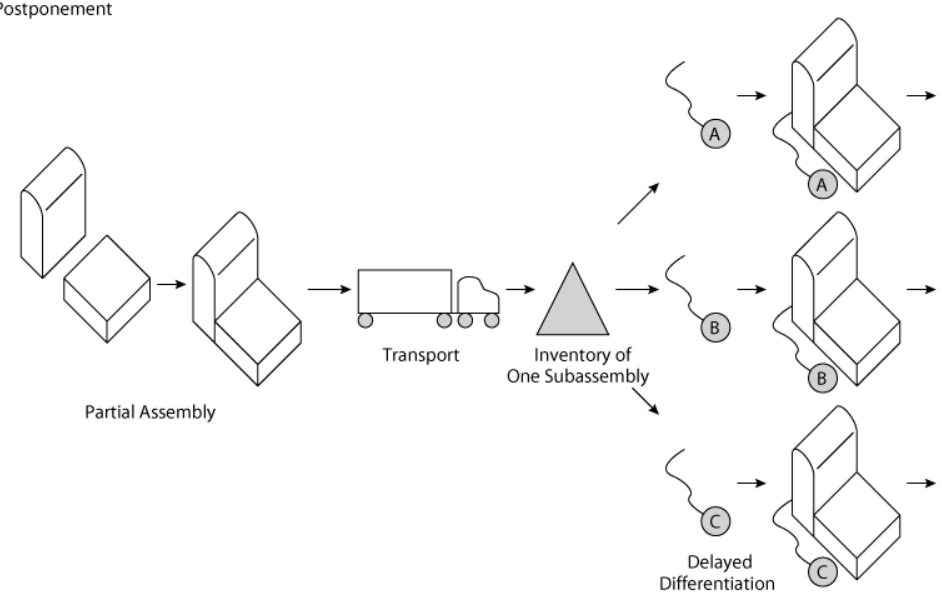
Benefits of Late Differentiation

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

Scenario A: Early Differentiation

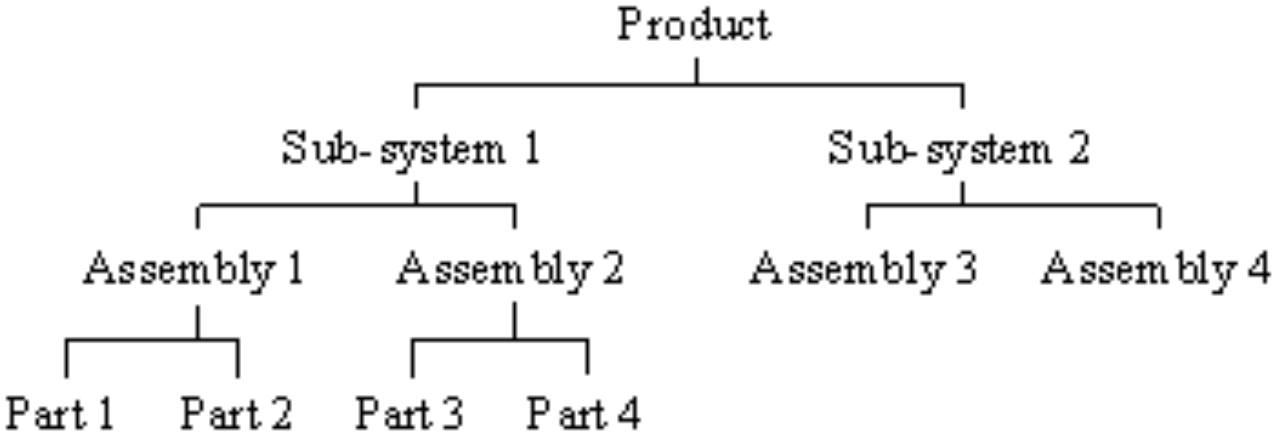


Scenario B: Postponement

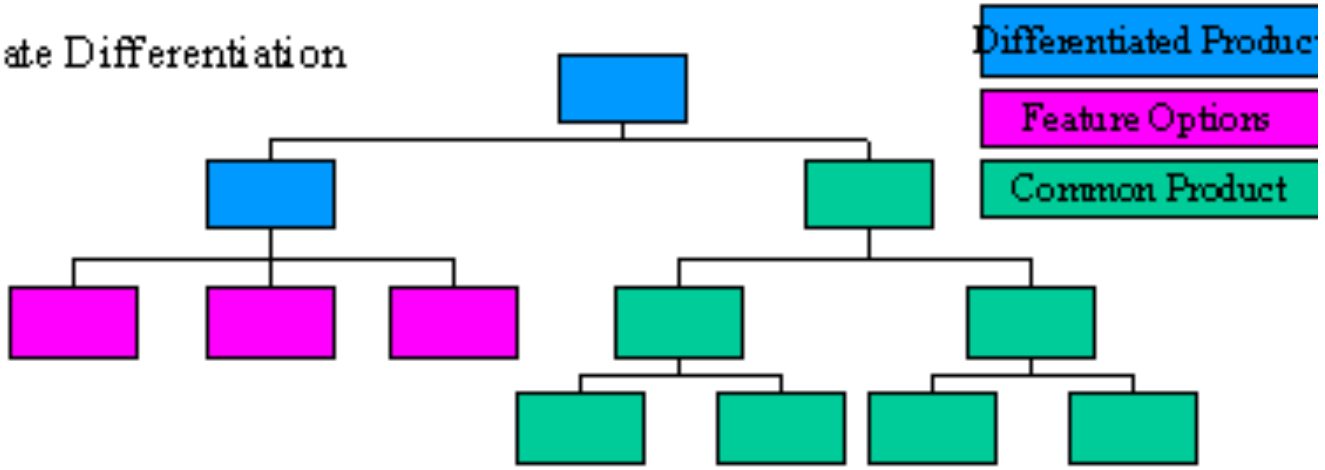


From *Product Design and Development* by Karl Ulrich and Steven Eppinger (McGraw-Hill/Irwin)

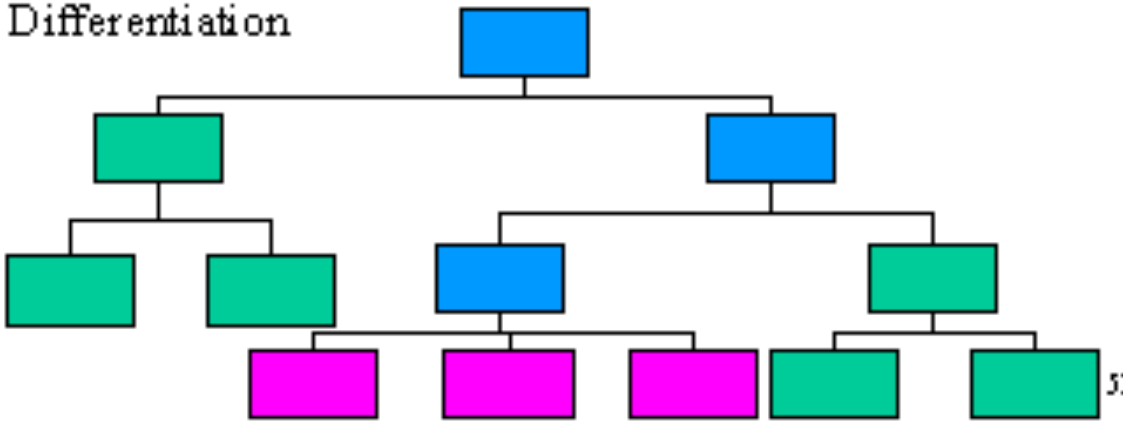
Assembly Sequence



Late Differentiation



Early Differentiation



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?

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

In-class exercise

- Your company manufactures and sells spinal fixation devices.
- Assume that the design concept is to secure a rigid body (e.g. a metallic plate) to adjacent vertebrae so that the unstable region is immobilized.
- Consider how product architecture could impact your design. Please note that your product needs to serve a population where spines come in a variety of sizes.
- What would be the embodiment of this design concept for a modular design?
- What would be the embodiment of this design concept for an integrated design?

In-Class Exercise 1:
Your company manufactures and sells spinal fixation devices.

Assume that the design concept is to secure a rigid body (e.g. a metallic device) to adjacent vertebrae so that the unstable region is immobilized.

Consider how product structure could impact your design. Please note that your product needs to serve a population where spines come in a variety of sizes.

What would be the embodiment of this design concept for a modular design?

What would be the embodiment of this design concept for an integrated design?

How do these embodiments impact late point identification.?