Modularity and the Geography of Innovation

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Overview

- Framework for thinking about modularity (and architecture) -- product, value chain, organization
- Looking at modularity through an industry lens
  - Computers -- the exceptional case?
  - Automotive -- how much change?
  - Mortgages -- evolution over time
- Architecture choices of firms -- alignment and misalignment; strategic choice
- Architecture-based capabilities of nations/regions
- Implications for Geography of Innovation:
  - Alignment of capabilities (national; organizational) to architectures
  - How location affects (and is affected by) architectural change

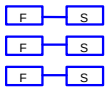
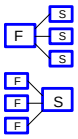
Modularity: Core attributes

- Design principle related to architecture of a system
- Seeking places of low interdependence between/among components (or activities) in a system
- Drawing a boundary there
- In some cases (but not all), seeking to standardize that boundary with respect to a domain (industry, firm)
- Ultimate goal: achieving separability at boundary, and minimizing coordination requirements across modules
- Opposite of modular is integral -- low separability and high coordination requirements across boundaries between components or activities in a system

Different Dimensions of Architecture

- **Product**: relationship between physical components and functions within a system (i.e. one-to-one vs. many-to-one, one-to-many mapping)
- **Value Chain**: integration or non- (dis-)integration of activities within a value chain (i.e. formalized and codified vs. idiosyncratic and tacit linkages between value chain stages, e.g. design-development-purchasing-manufacturing-distribution-sales)
- **Organization**: whether activities are contained within a single organization and a single governance structure, or distributed across two or more organizations/governance structures

Icons Representing the Three Dimensions of Architecture

Architecture	Modular	Integral
Product:		
Value Chain:		
Organization:		

Past Work Often Examines Pairs of These Architectural Dimensions

- IMVP Modularity and Outsourcing Project (e.g. Sako, 2002) -- **Product** and **Organization**
- *Clockspeed* (Fine, 1999, 2005) -- **Product** and **Value Chain***
- Global Supply Chains (e.g. Gereffi, Humphrey, Sturgeon, 2005) -- typology combines **Value Chain** and **Organization**
- Outsourcing of Tasks and Outsourcing of Assets (Sako and Helper, 2007) -- **Value Chain** and **Organization**

My argument: Understanding the impact of architecture on geography of innovation requires examining all three dimensions (and *hybrids*)

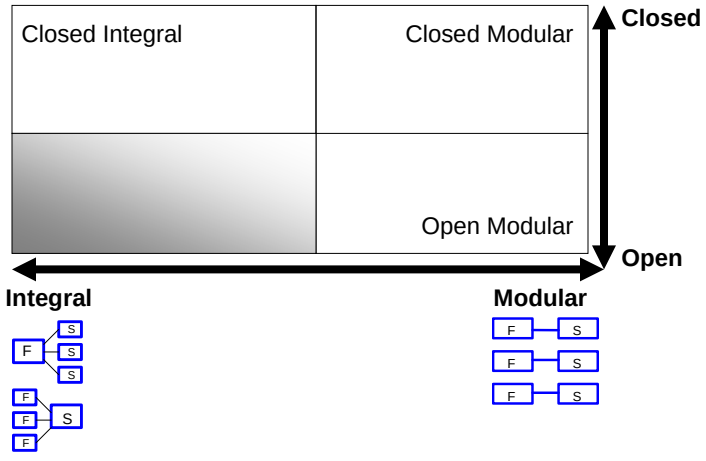
Product **Value Chain** **Organization**

* NB: Fine's 3D Concurrent Engineering Model includes Process Architecture too, not considered here

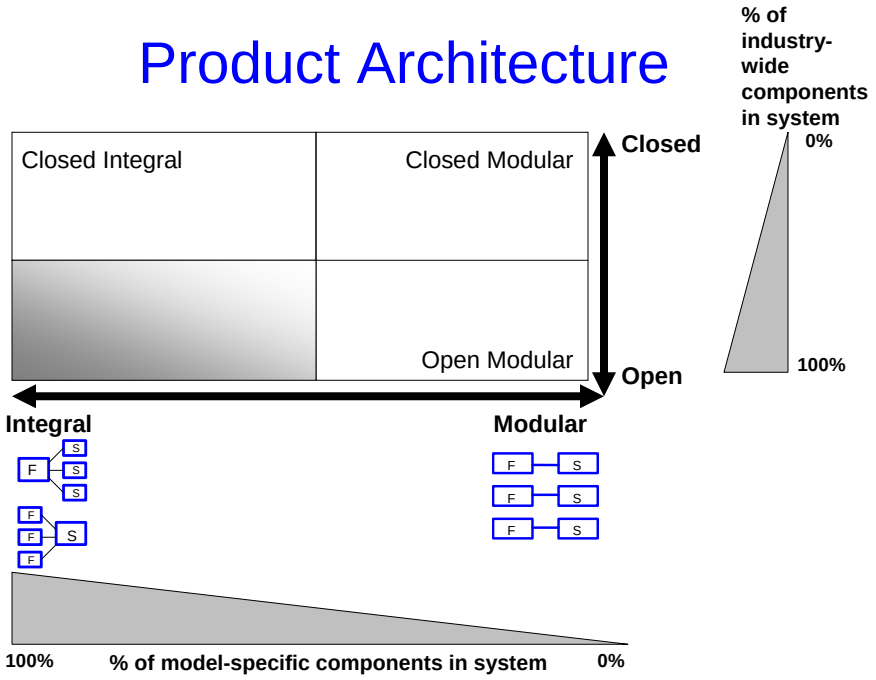
Alignment, Life Cycle, and Directional Logic

- Effects of architecture (including on location) are strongest with alignment across all dimensions, e.g. **Modular** Product & Value Chain & Organization
- Many cases in which dimensions are not aligned
  - Some represent Trouble (with a capital T)
  - Some reflect transitional states
  - Some provide opportunity for innovation and differentiation
- Different life cycle theories
  - Most agree: new technologies often start as integral and move towards modular
  - Most technologies will alternate between integral and modular phases over time
  - Related theories for industry evolution (e.g. Fine & Whitney; Baldwin; Jacobides)
- One directional logic is: **Product** → **Value Chain** → **Organization**
  but can also see examples of:
  Value Chain → **Organization** → **Product** *or*
  Organization → **Product** → **Value Chain**

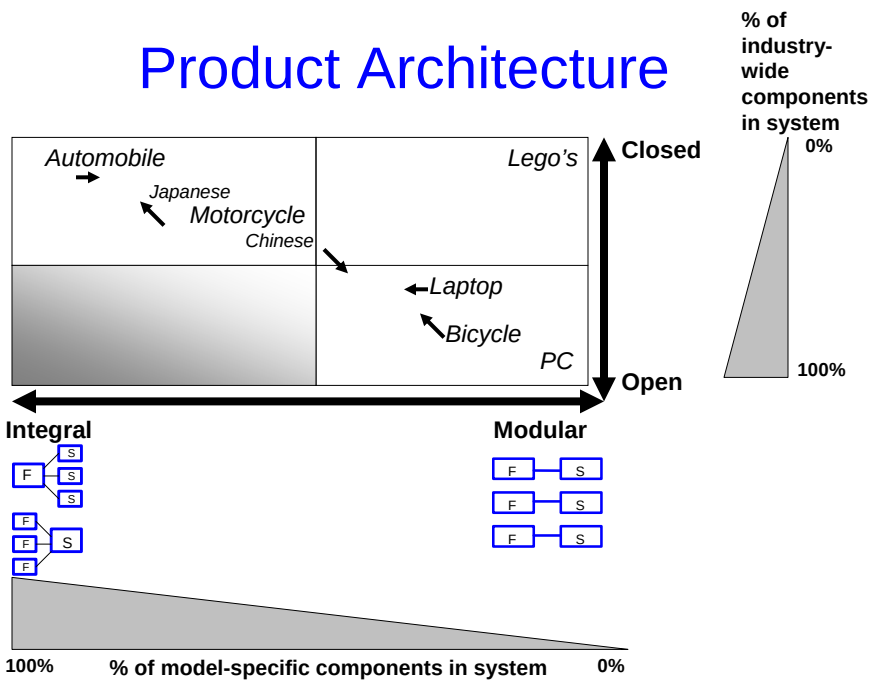
Product Architecture



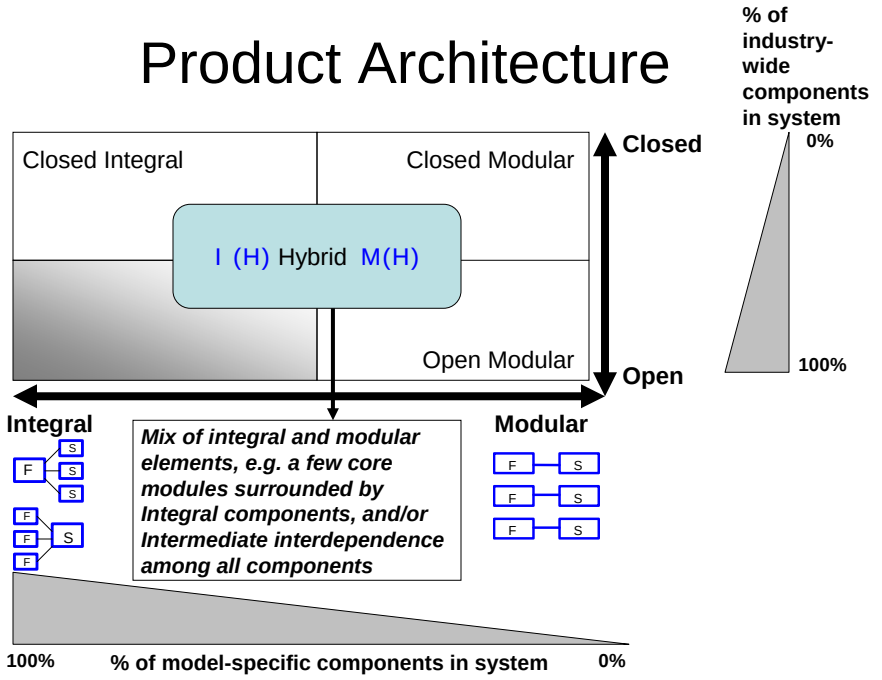
Product Architecture



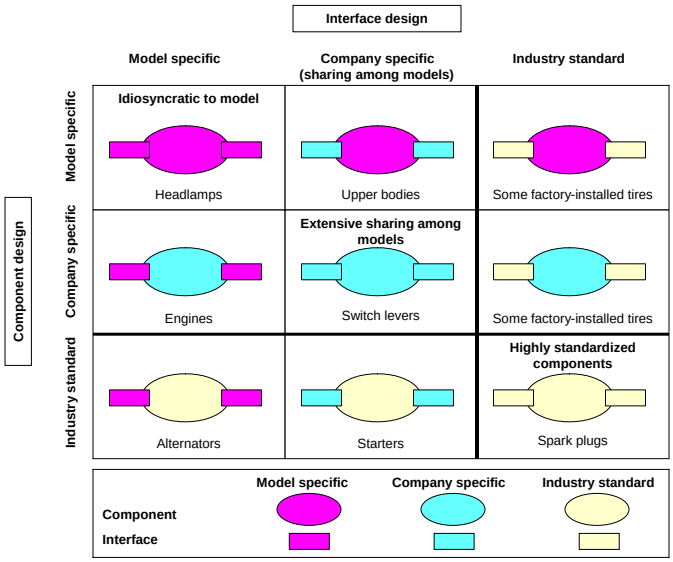
Product Architecture



Product Architecture



Automobile Product Architecture Is Hybrid Mix of Closed/Open & Integral/Modular Components Within Mostly Integral Architecture



From Takahiro Fujimoto (2007), *Competing to be Really REALLY Good* (translated by Brian Miller), Japan: LTCB International Library Trust.

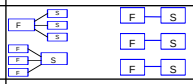
Value Chain Architecture

-  = M: formalized, codified, specifications determined up-front, coordination- minimizing
-  = I: tacit, idiosyncratic, specifications are emergent, interaction-intensive and non-routine
- Hybrid = M(H); I(H): *either type of hybrid* can be mix of pre-determined and emergent specifications *or* routine interactions to adjust and finalize specifications

Organizational Architecture

-  = M: separated (outsourced; spin-off; market; mechanical logic; open)
-  = I: integrated (vertical integration; alliance; organic logic; closed)
- Hybrid = M(H); I(H): hybrid collaborative mode (relational contracting; integrated network; open to new entrants but long-term relationships; “voice”)

Architectural Combinations

	Product (P)	Value Chain (VC)	Organization (O)
P – VC - O Combination			
I-I-I	I	I	I
I-M-I	I	M	I
I-I-M	I	I	M
I-M-M	I	M	M
M-I-I	M	I	I
M-M-I	M	M	I
M-I-M	M	I	M
M-M-M	M	M	M

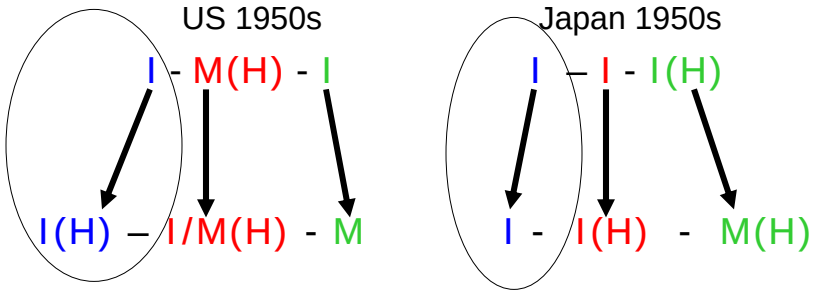
Misaligned Combinations

- From perspective of technology-driven change in product architecture (Chesborough and Kusunoki, 2001):
  - (I→M)-I-I is "integrality trap"
  - (M→I)-M-M is "modularity trap"
- From evolutionary perspective:
  - Value chain codification is expected as technologies mature, so I to I(H) to M(H) to M is incremental change
  - Likelihood that organizational separability will follow value chain codification, often with lag, i.e. outsourcing easier once VC= M
- When firms have capabilities for misaligned combination:
  - They may be able to innovate within that combination
  - They can gain major strategic and competitive advantage
  - Achieving hybrid architecture, on any dimension, reduces strain and risk from misalignment

Computers: Exceptional case?

- Personal computers are much closer to pure modularity than almost anything else -- M-M-M -- but they may be an exceptional case
- Designs based on VLSI principles, with low power, are different fundamentally from designs based on complex electro-mechanical-optical (CEMO) principles, with high power (Whitney, 1996, 2005)
- CEMO products generate systemic side-effects (e.g. heat, vibration, noise) for which design remedies are required -- component tests don't answer questions about system performance
- VLSI components can be designed with logic that matches one function, testable in advance, component will perform the same during initial test and when installed in system
- Many mistakes (strategic in business, analytic in research) from extrapolating from personal computers to other products

Industry Examples: Automotive Change Over Time



In mid-to-late 1990s, GM, Ford, Chrysler are enthused about prospects for modularizing vehicle architecture

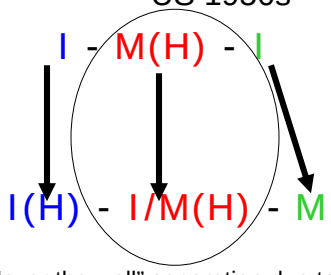
US 2007

Japanese automakers are mostly skeptical of modularity and maintain integral vehicle architecture

Japan 2007

Industry Examples: Automotive Change Over Time

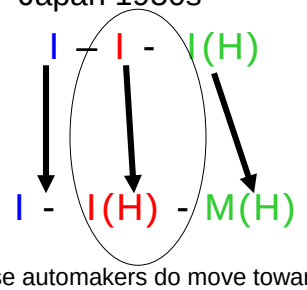
US 1950s



Less "over the wall" separation due to increase in overlapping PD, but also activities more precisely specified via platform architecture & digital processes

US 2007

Japan 1950s

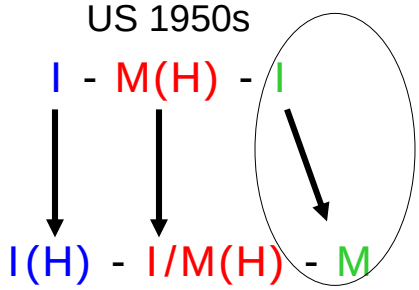


Japanese automakers do move towards more codification, but implement IT tools more slowly & still do lots of integrated up-front problem-solving with suppliers

Japan 2007

Industry Examples: Automotive Change Over Time

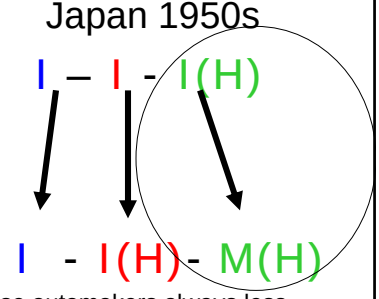
US 1950s



GM & Ford shift away from vertical integration with creation of Delphi & Visteon, and actively pursue outsourcing, using "China price" as leverage

US 2007

Japan 1950s



Japanese automakers always less vertically integrated, yet close relational ties to suppliers -- with breakup of *keiretsu* closed networks, new suppliers can enter, but still long-term contracts

Japan 2007

Industry Examples: Mortgage Industry Change Over Time

- Mortgages (from Jacobides, 2005):

I-I-I (1950s) →

M-I-I (early 1970s) → "mortgage-backed security"

M-M-I(H) (1978-88) → secondary market for loans

M-M-M(H) (1983-87) → brokers

M-M-M (1989-93) → servicing rights

M-M(H)-M(H) → (2007-10?)

tighter regulation, more interdependence?

Company Examples (Fine 2005): Alignment of Architectures

- Toyota: I-I-I
- Dell: M-M-M
- Cisco: Product portfolio differs by architecture, but all are aligned

(I-I-I)-(Hybrid in all 3)-(M-M-M)

Company Examples (Fine 2005): Misalignment of Architectures

- Polaroid: from I-I-I to I-M-M
- Lucent/Nortel: from I-I-I to I-M-M

I-M-M seems to be a serious misalignment

Firm Strategic Choice re: Architecture

- Firms that have strong capabilities in a particular architecture can deploy them strategically (Jacobides, 2007) by:
  - Leveraging those capabilities by developing products with that architecture
  - Differentiating by changing (or applying them to a different) architecture
- IBM – firm with strong integral capabilities changes the game via M-M-I/M (360 mainframe/PC) (Baldwin and Clark, 2000)
- Shimano – innovating in architecture, from M-M-M to M(H)-M(H)-I(H) via integrated shifting/braking (Fixson and Park, 2007)
- Apple iPod
  - Product is I(H) (closed with key modular components), value chain is M(H) (interaction-intensive for development, codified for manufacturing), organization is M(H) (relational contracts)
  - Plus business model integrates product with iPod and iTunes software and complementary services (Music Store, podcasts, etc.) -- **overall, a hybrid with strong integral elements that resist imitation**

National/Regional Architectural Capability (Fujimoto, 2006)

- Starting from Ricardian competitive advantage:
  - A country richly endowed in a particular asset/resource gains advantage for related goods/services when trading with countries that are comparatively weaker
- Country (or region) has an historical path
  - A group of firms in the same country or region, facing similar environmental constraints, national-regional institutions, demand patterns or other forces specific to a particular geographical area may develop similar types of organizational capabilities
- Products with architecture that fits this organizational capability tend to demonstrate competitive advantage
  - Product advantage doesn't guarantee profitability

Fujimoto: Architecture-based Comparative Advantage

Japanese firms -- integration capability
More competitive in products with *closed-integral architecture*.
based on *integration-based manufacturing capability*

Chinese firms – mobilization capability
More competitive in labor-intensive products
with *open-modular (or quasi-open) architecture*

Korean (large) firms – concentration capability
More competitive in capital-intensive products
with modular architecture (moving toward integral?)

ASEAN firms (e.g. Thailand) – labor-retaining capability??
More competitive in labor-intensive products
with closed-integral architecture?

U.S. firms – conceptualization capability
More competitive in knowledge-intensive products
with *open-modular architecture*

European firms – expression capability
More competitive in *closed-integral products*
based on brand-design-marketing capability

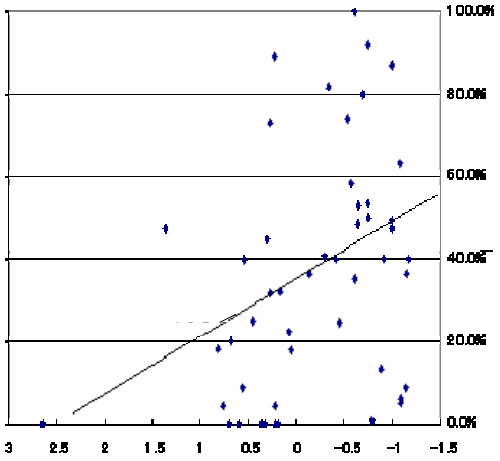
C Takahiro Fujimoto, University of Tokyo

Japanese Firms Have High Export Ratio for Integral Architecture Products

Examples of integral architecture products:

- **Passenger vehicles**
- **Motorcycles**
- **Video games**

See Sturgeon, (2007) on how Japanese firms compete in consumer electronics



Export Ratio from Japan

Integral Architecture Index

C Takahiro Fujimoto and Takashi Oshika, University of Tokyo

Country Example: Taiwan

- In Fujimoto's framework, Taiwan can support integral architectures for Japanese customers and modular architectures for U.S. customers

  Product = I or M

- Integrated supplier network operating at industry level is key resource -- lots of interaction, relational contracts

  VC = I(H) and Organization = I(H)

- Over time, these capabilities pull more value-added activity to Taiwan

Industry Example: Laptops Location Change Over Time

	Architecture	Design	Dev'lpment	Mft'ing
1995	M(H)-M(H)-M(H)	U.S.	U.S.	Taiwan
2000	I(H)-M(H)-I(H)	U.S.	Taiwan	Taiwan
2007	I(H)-I(H)-I(H)	Taiwan	Taiwan	Taiwan-owned in China

- Architecture is always hybrid -- some key modules, many integral components for fit and features -- so design-development interdependence
- Always some interdependence between development and manufacturing, given mft. challenges re: size and weight
- First, pull of development to Taiwan, within ODMs -- to I(H) -- and, as product complexity grows and integrality increases, product arch. to I(H)
- Now design is pulled to Taiwan as well -- I(H) – albeit in U.S. R&D labs

Source: Dedrick and Kraemer, 2007

Country Example: Taiwan's efforts to strengthen competitiveness of bicycle industry

- Two leading bicycle companies (Giant and Merida) and government worried about competition from China
- A-Team launched in 2002: collaboration effort between Giant and Merida (OEMs) + gov't. support
- Joint OEM & supplier effort to implement Toyota Production System
- Joint product design/development between OEMs and shared supplier base -- long-term contracts, integrated supplier network
- Giant: Product design more integral (integrating frame, suspension, electrical transmission system, lighting) I(H)-I(H)-I(H)
- Merida: More product variety to reach different consumers, hybrid modular designs, more model-specific parts M(H)-I(H)-I(H)

Source: Liu and Brookfield, 2007

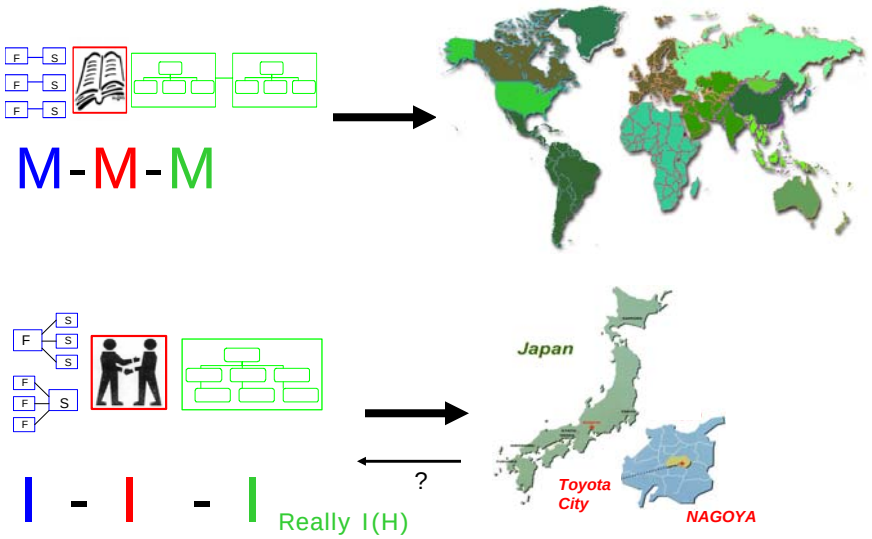
Different Dimensions of Architecture: Which Matter Most for Geography?

- **Product**: Specification of module boundary and interface **facilitates separability**, makes distribution of tasks over distance feasible
- **Value Chain**: Codification/formalization at linkage of activities **facilitates distribution** of tasks over distance
- **Organization**: Moving activities outside a firm's boundary to a supplier facilitates independent locational choices by supplier, on industry basis -- **accelerates distribution** of tasks over distance
- Interaction with customers can be essential to gain access to knowledge affecting product and value chain architecture
- Need for customer interaction creates "pull" for proximity -- integrative counterbalance to pressures for separability and task distribution

How Does Geography Matter for Different Dimensions of Architecture?

- Proximity offers many advantages for work on interdependent tasks
  - People work from the same information
  - Groups share an identity, develop a culture, are more readily motivated
  - Teams can resolve conflicts and learn more quickly
- Distributing work over distance disrupts these advantages. Consequences are greatest when task interdependence is high.
- **One remedy is increased modularity to reduce required coordination**
- **Alternate approach: Increase organizational capacity for coordination-intensive activity** – needed when architecture is mostly integral
- Virtual team members can develop information congruence and shared identity through careful attention to team formation and establishment of routines that compensate for lack of proximity
- Regular opportunities for face-to-face interaction at critical moments of interdependence often still necessary

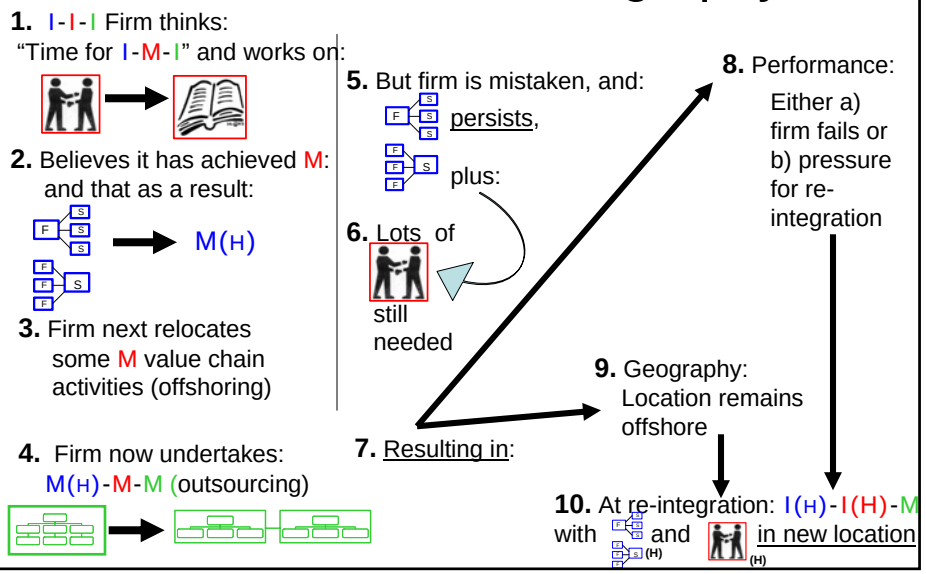
Alignment: Implications for Geography:



Most Common Misjudgment

Hypothesis: Believing links between value chain stages are well (and completely) codified

Misalignment: Implications for Performance and Geography



Implications for Jurisdictions

- Become aware of architectural capabilities of firms & architectural trends of industries
- Firms will seek opportunities to leverage their capabilities but may also seek differentiated advantage through new capabilities accessible in new locations
- Fastest entry possibilities are in supporting modular products with well-codified value chains
- Greatest "pull" of additional value-added activities comes from more integral products -- I(H) -- whose value chains still require extensive interaction -- I(H)
- Ability to support firms with industry-level suppliers that have separate governance yet form a tightly integrated network – I(H) or M(H) -- provides capabilities for either I or M products

Conclusions

- Modularity as Rorschach -- different people see different things
- Important to consider multiple dimensions of architecture, in combination, including hybrids
- Firms can achieve major gains from successful architecture-based strategies -- or make big mistakes
- Jurisdictions can benefit from an architecture-based assessment of what products, value chains, and organizational models they can best support
- Knowledge of architecture allows anticipation of how dynamics of separability and interdependency will affect future location decisions