

# **Technology Structure and Intersectoral Diffusion of Technology**

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(Very Preliminary Draft)

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## **Abstract**

The paper responds to Rosenberg's quest to the internal logic of technological change. Compared to the path-dependent adoption of standards, inter-sectoral technological diffusion is less dependent on the demand state. Rather it is a result of the interrelated characteristics of technologies and the nature of the inventors' combination of different knowledge. Evolutionary economics has achieved various results from simulations with random technology variables. This has often been criticised for its lack of empirical data. This paper explores technology proximity as a key concept to understanding intersectoral diffusion of knowledge and insists that engineering representation can be used for evolutionary modelling with proper use of graph theory. Also it examines the utility of the patent system for the interpretation of technological

structure.

## Introduction

Intersectoral diffusion of technology is a natural phenomenon because distribution of technology is not confined by product sectors<sup>1</sup>. Much of the literature on intersectoral diffusion reviews the story of how the cost reduction in key technologies created massive demand. Despite its apparent significance, there is frequently little explanation about how much the cost reduction is viable<sup>2</sup>. Reduction of cost or continuous improvement is considered to be associated with complementary technologies (Helpman and Trajtenberg, 1994). Also this cost reduction is frequently accompanied by a swarm of innovation clusters. Clustering of innovation is not serendipitous but is systematic interrelated technical development (Freeman et al, 1982; Rosenberg 1982 Inside Black Box; Sahal, 1983, TFSC). This raises the following question of why the various technologies are likely to be interrelated to one another?

The affinity of the technologies that underlie complementary technology clusters is central to understanding the internal logic of technological change. This paper looks at the possibility of embracing technological affinity.

A specific technology can be widely used if it interfaces with a prevalent artefact or activity. For example, cutting technology is a general-purpose manufacturing technology only if machines are made of steel<sup>3</sup>. If the machines were made of clay, it would not be a general manufacturing technology. If a technology interfaces with general materials or artefacts like machines, it can be used over wide sectors.

Engineering textbooks describe technology as a system through which material, information, or energy is transformed. This representation is powerful enough to explain inter-sectoral diffusion. An optical technology like the laser is widely used in various sectors. The laser is a form of energy transfer with high control and efficiency. Its time-control aspect is linked to information processing. Also it can be used as pure energy for cutting and welding. Any technology that has significant linkages to material, information, or energy can be a general-purpose technology. Complementarity originates from non-exclusive asset sharing or sequential positioning. The linkage structure that defines complement any technology is an important issue

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<sup>1</sup> For the technology-industry matrix, see Patel and Pavitt (1997)

<sup>2</sup> Pavitt insists that there is a technologically determinant factor in cost reduction, giving the example of micro-electronics contrasted with nuclear energy (informal discussion)

<sup>3</sup> A deeply embedded condition is that the machine is a general method of producing physical goods and human satisfaction is normally derived from tangible physical goods rather than electronic stimuli directly into human brain; this techno-social dimension is not dealt with here.

for diffusion. Rapid diffusion of a new technology is viable when the technology conforms to knowledge frontier in every aspect: information, material, and energy.<sup>4</sup>

## 1. Search , Proximity, and Structure

### 1.1 Search

Following Schumpeter's concept of combination, innovation is a combination that causes qualitative changes and increases variety. Referring to the three conditions for evolutionary economics - variation, selection, and retention - combination is in the centre of variation (Andersen, 1994). In this paper, we confine our focus to the technological aspect of combination.

The generation of new technology is combination of previous components and processes. Basalla (1988) depicted this connection as the result of similarity between required function of new artefact and unrealised function of old artefact. Even the electric light bulb has its ancestors. Revolutionary technology such as turbojet aircraft has its antecedents in the combustion engine, the heat pump, and turbine blades (Constant, 1980). The probabilities of combination can be changed by the emergence of new complementary artefacts and scientific knowledge (e.g. the electronic motor, the Maxwell equation on integration of electric-magnetic fields).

Searching for solutions of a problem set is a process of combination. When the search reaches an end, it entails new combinations in the technological domain. The search process depends on inventors' cognitive skills. Technological imagination is a metaphor with which inventors combine diverse artefacts and is influenced by the current image of physical artefacts<sup>5</sup>. Diversity of the search path is heavily influenced by diverse perception of physical artefacts. Therefore, it is worth questioning whether artefacts can be classified within a general scheme because the classification reflects the inventors' paths of search. For example, using common-

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<sup>4</sup> The fundamental question is why the geography of technology is in its current shape. De Solla Price (1984) indicated that every new technological discovery should fit into the current technology frontier like pieces in a jigsaw puzzle. The current knowledge frontier defines the fitness of new knowledge. Therefore, the current state of technology is an accumulation of these fitting processes. Vincenti (1990) also insists that Campbell's blind variation should be understood in conjunction with cumulativity and conformity. The boundary of random variation is confined by the current technology frontier.

<sup>5</sup> Ferguson (1992) emphasises the visual aspect of technology. This is evident in the design of components. Nightingale (1998) states that the metaphor used for technology should be bi-directional. In that sense technological knowledge is different from that of science, which is more unidirectional description.

sense, we can say that aircraft and automobiles are the same in terms of transport means. However F1 cars are not produced for transport. The definition based on the service purpose is not necessarily consistent with the design principle. In other words, engineers' search direction is largely bifurcated into design and function (Gorman, 1997; Sahal, 1985). A unique static classification can hardly accommodate these dual paths of searching.

Search is biased towards social values. There are at least two social selections made before an idea reaches innovation stage, the inventor's evaluation of potential demand and post-selection in market and society (McKelvy, 1994). However, variation in a diverse social group is likely within the definite guideline - technological feasibility. Social or economic values give more frequent search chances to certain directions of research and select the results of successful search, but the search process itself is controlled by technological feasibility.

## **1.2 Proximity**

Nelson and Winter's Model includes the probability of a successful search as an inverse of technology distance. Levinthal and Cohen (1989) also emphasise absorptive capacity based on "similar skills". It is commonly accepted that mastering a skill makes absorption of a similar skill easier. Both learning and selection are confined by technical proximity.

Sahal (1976) explored the distance concept to measure technical change. His work is mainly dedicated to measuring progress of technology, not for cognitive search space. But his notion of within-group and between-group distances is pertinent and will be discussed later. Jaffe (1986) implied technological position to exploit knowledge externalities. His use of patent subclasses as a unit of proximity measure has strong empirical implications. However, the introduction of distance is still controversial for the patent subclasses are not independent of one another. The question is, if a firm has a strength in A technique (patent class), can the firm derive benefit from neighbouring firm's B technology that is closely related to A? If we measure technological competence at patent class level, this can be a more serious question. Therefore, it is useful to examine whether patent subclasses are structurally linked and whether we should take this into consideration. Thus, the question on proximity turns out to be one of linkage structure.

Before discussing structure, the following question should be answered.

- What is the unit of technology?

Identifying the unit is central in an evolutionary context (Boulding, 1978 cited in Anderson, 1994). Unlike a well-defined biological unit (DNA), technology has no concrete units. As Granstrand (1994) confessed, the unit of technology set is an unsolved enigma in his model, and

is very fundamental issue for any efforts to pursue technological distance. Fleck (1998) enthusiastically introduced the unit that fits de Solla Price's concept of the Jigsaw puzzle. He suggests that the artefact-activity couple is a proper description for a technological species. But his concept that activity includes organisational factors and knowledge is not fully disclosed for practical representation. Saviotti and Metcalfe's model (1984) is compatible with Fleck's concept of couples and contains detailed representations such as the linkages between process (activity), technical (artefact), and service characteristics. Service characteristics such as power, speed, noise etc, are actually linked to the activities of users, so it presents the activity-artefact-activity linkage. We accept this representation as a proper unit<sup>6</sup>. This is a modified form of input factors - process (the so called black-box) - output products framework: artefact- activity-artefact framework.

Under the input-output representation it is possible to measure input and output proximity separately with an attributes list. At the industry level, distance between industry is measured simply as the sum of squared deviation (Burt and Carlton, 1989). The row and column comparison of the input-output table produces an aggregated index. If we extend the similarity to second linkages (indirect similarity), it is possible to grasp a potential similarity between seemingly different technological fields. Callon introduces Doreian's strict and regular equivalence to diffusion of technology (Doreian, 1988 cited in Callon, 1993). By using the network concept, he explores the transition of the adoption process amongst heterogeneous actors. The regular equivalent emphasises this similarity based on indirect linkage structure<sup>7</sup>. Complex linkages cannot fully explained by metric Euclidean measures<sup>8</sup>. The indirect similarity has theoretical implication if we assume a hierarchical structure of technology. Technologies belonging to the same hierarchical branch can be close each other.

### 1.3 Structure

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<sup>6</sup> The proper size of the unit is also important. If we evaluate gene similarity by looking at just the share of four-bases (A, T, G, C), no meaningful classification can be made. The evaluation should be based on a set of coupled bases. To reduce the proximity of classification tree to shares of attributes is dangerous without a proper unit of attributes.

<sup>7</sup> Proximity values can be enhanced by calculation of indirect linkages. The University of Leiden uses group data (column) to modify individual level proximity. Hwang (1997) also confirmed that proximity, including indirect linkages, is more accurate when compared with the cognitive proximity of experts.

<sup>8</sup> Granstrand (1994) use metric measure. The technological distance in sigma algebra adopted in Granstrand is

actually analogous to the proximity value suggested in Callon et al (1986)  $P_{ij} = \frac{C_{ij}^2}{C_i C_j}$ , the only

difference is he used a complementary set to describe a distance value.

In the vein of Herbert Simon' notion, complex systems might be expected to be constructed in a hierarchy of levels. The question is whether technology system is hierarchical because of its artefacts.

Historians like Constant (1980) identify two hierarchies: those of design in a system and of selection practice. In the business literature, Marple (1961) and Clark (1985) stress the importance of hierarchical structure in a system. Clark introduces another hierarchy, the consumer's concept, according to which inventors investigate possible production innovations. Actually the hierarchy of consumers' concept is analogous to the hierarchy of perceived service function. The hierarchical perspective is a powerful tool to analyse the search for design change of individual systems. However, hierarchy in a system cannot be applied generally. The problem is the consumers' concept is less hierarchical and even inconsistent with physical hierarchy. The order of components in the hierarchy varies across systems.

In biology, specific skills for measuring the distance of species are well developed and species distribution structures can be built on the distances<sup>9</sup>. These distances enable us to build a general hierarchy of species, but there is no counterpart in technological knowledge<sup>10</sup>. The existence of a hierarchical structure of technology remains unproven.

In scientometrics, a hierarchical figure appears when we focus on the organisational aspects of knowledge. The well-known Lotka law (the Matthew effect) indicates concentration of publication. However, when we describe the distribution of technical knowledge in terms of title and keywords in scientific and engineering papers, which is a more pure knowledge excluding authors - social agents, the hierarchy is not a proper term. Cunningham (1996) describes disciplinary field as an amorphous co-existence of a horizontal network and vertical trees after analysing a bibliometric distribution. His finds the distribution of terms does not fit Zipf. It is rather a Levy distribution, which invalidates the hierarchical knowledge structure.

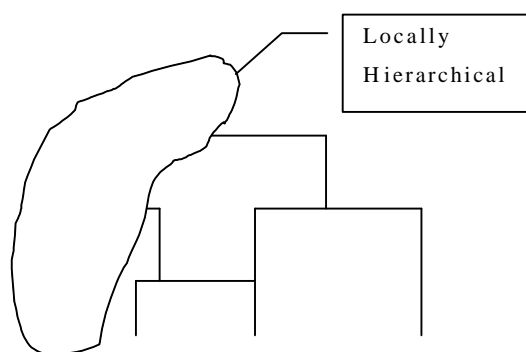
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<sup>9</sup> On the economics of biological variety, Weitzman (1992) suggested an iteration method to find the best fit for ultrametric structure (hierarchical). His notion of distance as a differential of variety is important if we can build a robust index for variety. The reverse calculation (not from distance to variety but conversely) can yield distance (inverse of proximity). However, applying the Shannon index requires using original reference only (main classification), in other words, a patent is strictly assigned to a patent subclass, which is too great a sacrifice for non-exclusive knowledge aspect.

<sup>10</sup> If we return to the proximity issue, distance under strict hierarchy can be evaluated with index-tree methods, but a holistic method for metric and topological evaluation is not available within current science frontier (Bahdi and Politi, 1998).

The inventor's mind navigates through pseudo-hierarchical space, which has only locally hierarchical branches and allows overlapping with other branches, which leads to the unique nature of technological evolution that allows the interbreeding of bifurcated branches (Basalla, 1988).

The overlapping of hierarchical tree is actually caused by treating independent variables as ordered criteria of the hierarchy. This is evident when we examine subclasses of the patent system (See, Appendix).



**Figure 1 Fragile Quasi-Hierarchy**

Hierarchy is normally represented by strict asymmetric influences between actors. In the case of technology, a higher hierarchy is an exclusive inclusion set for sub-set. A technology defined as "Ultra-Violet light which is emitted from a sapphire" belongs to "radiant energy which is emitted from a crystallised material". However, it is ambiguous to decide whether "laser from transparent material" also does. Normally classification problems occur in material (artefact) aspects because too many horizontal criteria exist. In the example above, material can be divided into transparent or non-transparent. There is no hierarchical relationship between transparency and crystal-type. Whether we divide material into transparent or crystal types depends on the situation of use. The priority is contingent upon specific problem domains. For example metal/ non-metal is not high priority when the function is simple packaging. If the function requires heat resistance then sub-criteria of non-metal, ceramic/non-ceramic is of prior concern.

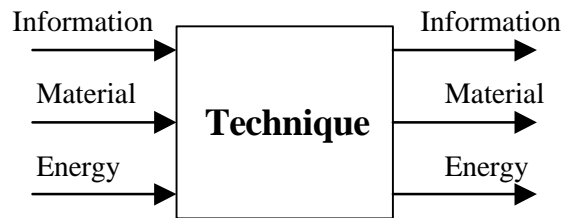
If the hierarchy is strict, variation is more likely to be confined within the hierarchy. In this sense, the source of diverse linkage that leads to intersectoral technological diffusion is a fragile local hierarchy under different service functions. To sum up, technological structure is overlapping multiple hierarchies because artefacts are multi-facet and the service function is context specific.

## 2. Engineering Representation

### 2.1 Representations

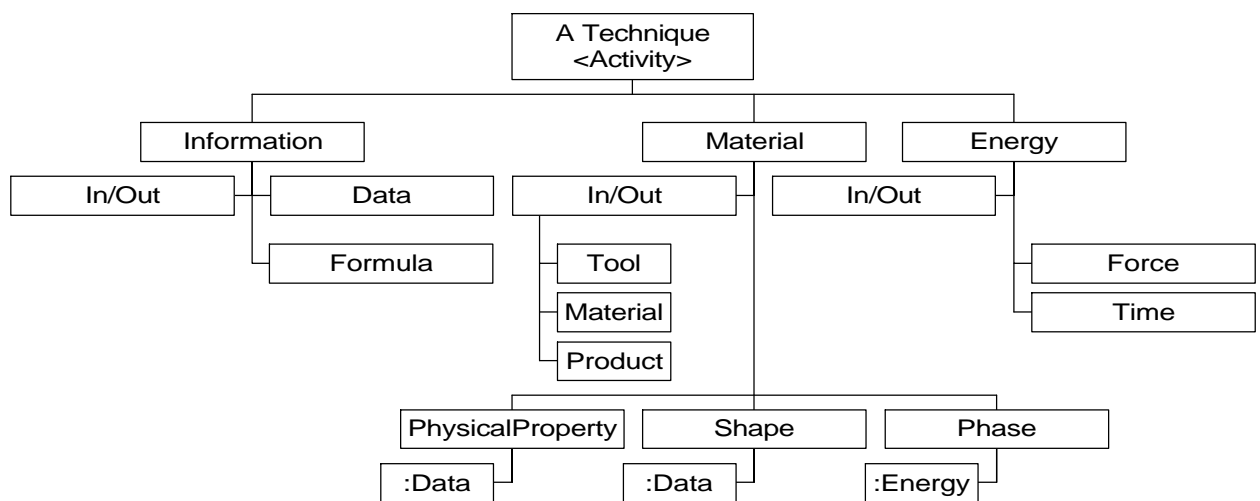
The structure suggested here is an engineering representation. It is based on hierarchical concepts, but the representation has some loose connections between hierarchical branches.

Information, Material, and Energy (I, M, E) are the input and output sides of an activity. In particular, material input can be divided into simple material and tools. Energy has two attributes, force and time, which have connection to material statue (i.e. liquid phase) and activity. As we can see in the relationship between energy and material state, all the three channels are related to one another. Data can be stored in a material form or transferred in form of energy.



**Figure 2 Representation of Technology in System Engineering**

The activity of technology in manufacturing is defined by three attributes, and the activity is the transformation between them. The quality of activity is defined by control level and span, because the evolution of technology has a general direction such as increasing diversity (Saviotti, 1996) and the sophisticated control of an artefact enables diversity (I, M, E).

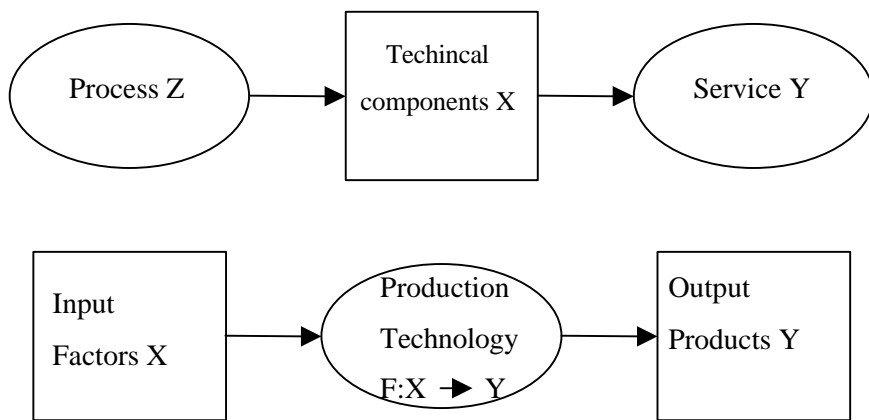


**Figure 3 Engineering Representation of Activity and Artefacts**

The use of this representation is two-fold. (a) to evaluate proximity qualitatively, and (b) to build a network model for the future.

Here, it is worth while to note the dual representation of technology. One is the well-known production function, and the other is described in the Saviotti & Metcalfe model (1984).

The production function approach lays emphasis on multiple factor inputs and output (recently output is also multiple). This representation is centred on the product. Abbreviation of the process as the black box works well for the boundary of economic transactions mediated with input- output price, though does not apply to technological change.



**Figure 4 Twin Representation of Technology**

On the contrary, the Saviotti and Metcalfe model concentrates on technological change.

The only difference between the two is that the production function puts definite price values on both sides but the Saviotti and Metcalfe model does not specify the values. Although the Saviotti and Metcalfe model can describe diverse modes of technological change, it does not aim to express the continuous flow of knowledge and artefacts. The ideal representation is to encompass both<sup>11</sup>. Engineering representation is similar to production function in its form, but it is also compatible with the Fleck/Saviotti-Metcalfe representation. The service characteristics are embedded in output with sophisticated definition and continuous vertical linkage to other activities.

## 2.2 Micro-flow of Technology

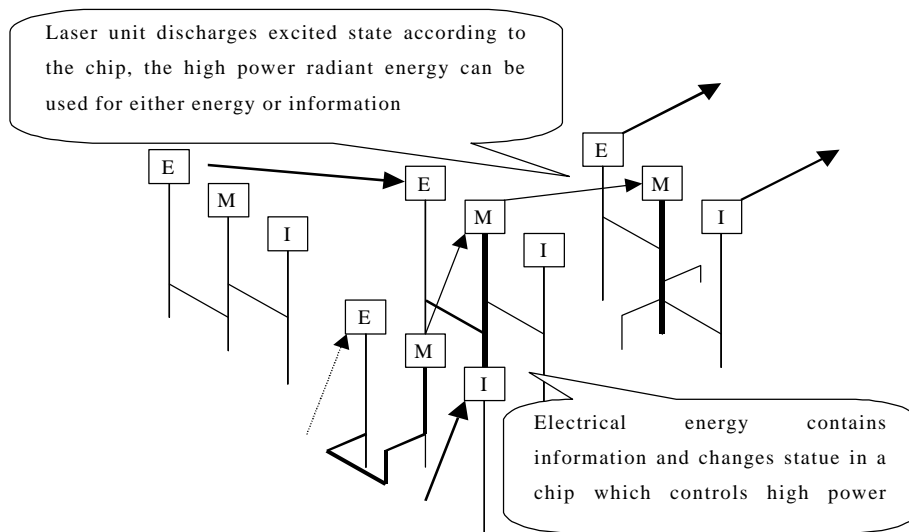
As noted above, the three attributes of engineering representation are not strictly separate. The

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<sup>11</sup> Real economic value is rooted in the service characteristic Y (activity), but economist can get data on tradable tangible goods only. A compromised method is to calibrate the value of activity as a gradient between known nodes of the network of continuous flows.

search process for combination is more likely to be high within the same attributes. Looking for a new material follows the path of material classification but in conjunction with another technology; a search process starts from M can cross boundary and reach E attribute. Therefore even if we build three separate Input-Output tables on information, material, and energy, the use of the tables is not straightforward because material-embodied energy and information give a dual interpretation. As a tool for imaging innovation, we can identify variation in the design of components and linkage, design of production processes, and function. A stimulation of the variations of the second and third kind is not confined to the boundary of an individual system but crosses the product boundary. The utility of an engineering representation is to describe the capricious flow-line of material, information, and energy.

The product defined by use is service functional linkage, and potential use stems from diverse steps in transforming its attributes (I, M, E)<sup>12</sup>. Therefore one of the most important feature of the current classifications is the frequent omission of the transformation direction. The transformation direction is a factor that decides the similarity between technologies.



**Figure 5 Example of Information, Material, and Energy Transformation**

Figure 5 shows an example. Electronic energy is controlled by small reference energy (function as data) and the power energy transform material to excited to emit radiant energy with

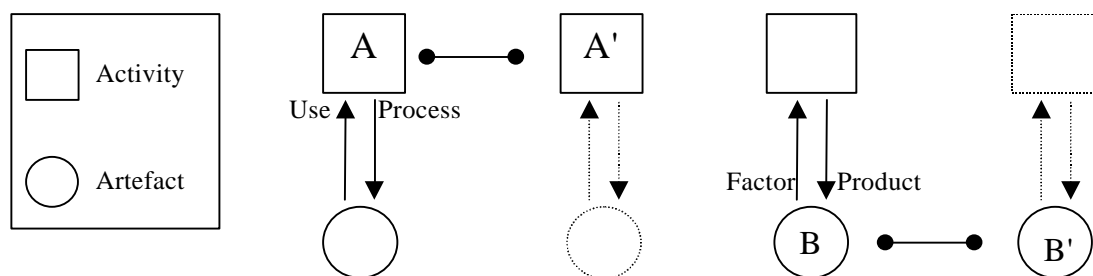
<sup>12</sup> Therefore it is possible to build linkages to the physical senses of humans. Visual information can be processed by the physical object, memorised and retrieved on paper, by scanning radiation to the eyes, or by directly stimulating the visual nerves. All these vertical streams are linked to different transformation techniques but have the same object.

information (amplified data for long-distance transmission).

As witnessed the unification between electric and magnetic forces, the hierarchical aspects and classification fit moderately for energy attributes, but not for material. Each technology unit should have a classification about three attributes, and this requires an extensive ontology<sup>13</sup>. Completion of the ontology leads us to the development of sophisticated modelling as a technological Input-Output analysis that envisaged by Schmookler (1966) and Scherer (1982). However the author supposes that the method be more flexible directed graphs rather than a strict rectangular matrix.

### 3. Proximity and Mode of Diffusion

Imaging similar patterns, extension of current parameters, and negative conversion are frequent methods used for searching an invention. Of these similarity is the most significant. Mode of intersectoral diffusion can be explained by a mapping of a similar activity-artefact relationship. The similarity between components in different sectors result in intersectoral diffusion of activity. Therefore technology proximity is a significant index for knowledge diffusion.



**Figure 6 Diffusion of technology by activity and artefact**

Figure 6 shows that case similar activities A-A' or artefacts B-B' induce the use of specific artefacts<sup>14</sup>. Even if the two cases look different, they are two sides of the coin. A technological

<sup>13</sup> There are efforts to make classification automatic. This is especially active in information science. For example, a team in Stanford University funded by DARPA is building a database on ontology. The objective is to create a new language that enables scientific knowledge to be easily shared.

See <http://www-ksl.stanford.edu/kst/what-is-an-ontology.html>

<sup>14</sup> For example, ion deposition in coating (charging particles) is applied to environment friendly painting; Mimicking an animal organ is a long tradition in invention (e.g. the aircraft wing); using a similar material for substitution (e.g. silicon instead of germanium).

development is a positive feedback between embodied and disembodied techniques<sup>15</sup>. If this feedback loop is shared by the two different sectors, it reinforces technological convergence. Therefore, a new set of technology that plays crucial a role to fill the gap in the feedback loop has a great potential. The intuitive logic of technological evolution such as technological imbalance (Rosenberg, 1976) and reverse salient (Hughes, 1982) describes it. This internal logic stems from a connected system. The bottleneck is the imbalance of quality amongst information, material, and energy. Thus, engineering representation is a better way to understand the dynamic diffusion of stimuli for technological evolution than representation with labour and capital. If the feedback is multiple and encompasses many sectors, a macro-effect, such as the creative destruction by a constellation of interrelated innovations (Freeman et al, 1982), is expected.

Even though technology has a vague boundary, there are feeding chains of technological flow. As alluded in previous section, the proximity and the closeness in vertical chain should be differentiated in use. Both contribute to the searching process, but adoption is more dependent on the existence of vertical closeness. That is, when two technology sets have high proximity, it is probable that there are potential partial vertical linkages between those sub-sets.

## **4. The Case of Emerging Technology: Rapid Prototyping and Tolling**

### **4.1 Rapid Prototyping Technology - Preconditions**

A new emerging technology field, Rapid Prototyping<sup>16</sup> (RP) is examined. Major RP technologies, such as stereolithography and selective laser sintering, are transforming powder and liquid material into solid 3D object by accumulation of layers with radiant energy. The main transform action is from material to reference value embodied artefacts. Our concern is how this new technology is formed by combination and how we can explain the situation with technological structure. For empirical reasons, we use the US patent and trade office patent system.

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<sup>15</sup> For example, innovation in heat treatment is a changing process of applied temperature of metal over a certain time period. If we produce a tool that controls temperature easily, a transformation of process to product gives another dimension for further development. The tool gives experimental power and produces a useful data set used for new process of heat treatment.

<sup>16</sup> The rapid prototyping system is capable of generating a 3-dimensional structure from CAD data within a few hours. Just as a pyramid consists of 2-dimensional squares, a 3-dimensional solid structure consists of 2-dimensional layers. The standard CAD data of a solid model is broken up into slices (layers). These slices are generated by RP machine, and the 3-dimensional solid structure is approximated by cumulated 2-dimensional layers.

Photolithography is used in the semiconductor industry for masking. This is well described in the case study of Henderson and Clark (1990). Highly cited by other RP patents, Patent Number 3932923, is assigned to an electronics corporation. However, the RP system is not the result of diversification of those firms. It is rather an inventor's exploration of technological proximity matched. Before the birth of RP technology, the precondition is mature enough to show vertical connection and technology proximity.

*Information* : A simple NC programme consists of controlling tool into X, Y, and Z reference values and indicating the tool spinning speed. Data processing for the positioning mechanical component is well developed in various machines, ink-jet printer, plotter, crane etc. The feedback control system increased the need for sensor technology<sup>17</sup>. The result is a highly accurate position handling component according to the reference data.

CAD data has been developed from a simple 2D environment to complex 3D, and during the course a discontinuous 2D section data into a more smooth 3D data was developed. Digital Imaging Technique (e.g. 3D scanner) is transforming physical figures into data.

*Material*: Grupp (1994) indicated laser and polymer sector is one of the most science based. At moment of introduction of RP, laser had been well developed for wide use. Photopolymer is a new material that changes characteristic (polymerisation) under radiant energy. The use of photopolymer is making a mask for printed circuit. Normally it is used for production of thin layer.

*Energy*: Heat energy is a traditional energy in forming article. Casting is also application of heat to make a more malleable fluid metal. Radiant energy was not useful for chemical reaction, as witnessed in photo films. The use of radiant energy was limited because of the control by lens. Laser technology provides a wide power band and high control of timing.

The abundant resources provided fertile soil for the birth of RP. The elements of RP such as control of scanning laser and layer elevation, photocurable resin, RP CAD data STL, could be envisaged.

The combination is also reflected in patent class level. Not specified as RP, co-classification between classes already embodied RP style combination.

#### **4.2 Intersectoral diffusion and Proximity**

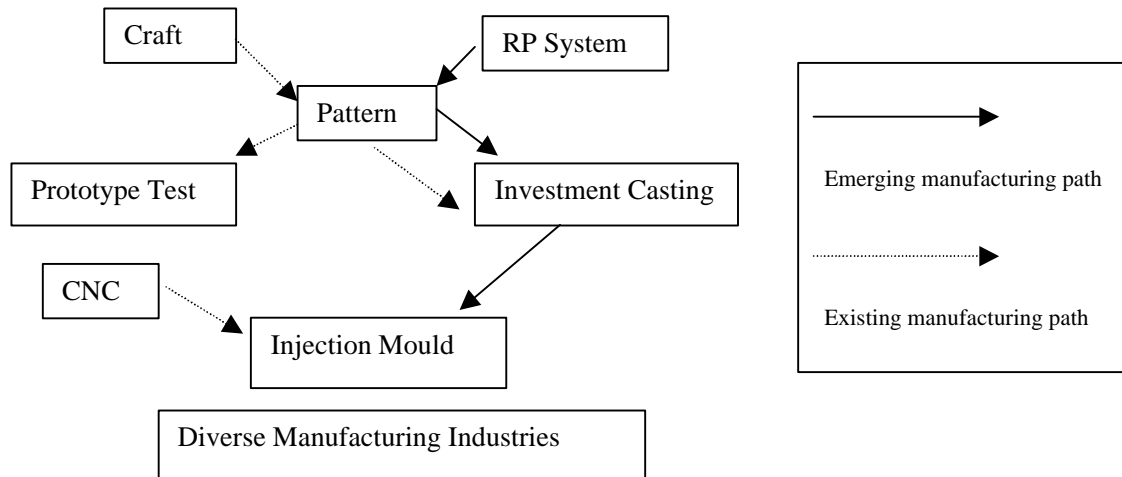
Intersectoral diffusion is normally reinforced by a carrier technology. In the case of RP,

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<sup>17</sup> Technology mapping near Factory Automation, see Granberg (1995)

investment casting is taking the role. Investment casting is usually used for casting complex parts in the aircraft and jewelry industries. Injection moulding technology is a widely diffused technology.

Investment casting started to be used for injection moulding with RP patterns<sup>18</sup>. Therefore it becomes more general with RP-investment casting combination



**Figure 7 Emerging manufacturing process and Diffusion**

The use of an emerging manufacturing path is exploiting the proximity between two artefacts, pattern and mould. Mould and pattern are also hierarchically in the same branch: 3D article with different material strength and heat endurance. Increasing quality and reducing cost enable the pattern used for the mould as well as a visual aid for design. RP pattern is complementary to NC when it is not used for mould but the RP mould becomes a rival. This implies that the relationship between technologies can change significantly from co-existence to a rival. The literatures on growth of new technology reported the importance of niche space in horizontal concepts. Technology that occupies niche space in upstream expands to downstream by improving the upstream part (whether it is a parallel process converging to a final process or in the same vertical line) resulting in another niche expansion, compressing the vertical chain. Change in vertical chains is a form of combination, which depends on the development of high-proximity between nodes. If the chain is long and high value added, then the impact of combination is enormous.

In a medical application, the diffusion is more information-oriented than in moulding. The empirical report of RP usage in the medical sector was just a few years after the realisation of

<sup>18</sup> 164/97 pertinent to investment casting increasingly appears in RP patents

moulding application<sup>19</sup>. The previous MRI and CT cross-section data is used for building concept models for surgical operations.

The transformation from 2D to 3D CAD data already existed, and the proximity is strong between RP input CAD data. Therefore affinity in medical cases is caused by input data similarity of RP technology

During the diffusion, vertical closeness is also very important as witnessed in the RP linkage to investment casting. RP pattern is an out-product of RP and also input for investment casting.

Medical graphic data is also linked to the middle of vertical chain between 3D CAD and RP system.

Finally, a positive feedback between the diffusion of technology and vertical disintegration is evident. As Rosenberg (1976) noted, previously similar processes spread over diverse sectors are resources for formal mechanisation of the process. This mechanisation entails vertical disintegration of craft process - pattern making crystallised into RP system, which opened the further possibility of diffusion into the medical sector. It embarks on dynamic learning amongst different user sectors and the performance/cost ratio improves.

#### **4.3 Interpretation of Patent System with Engineering representation**

The patent system is one of the most technology oriented classification systems. However, the class has no explicit indication of Information, Material, or Energy flows. The manual on classification provides useful information on interpretation, an example on RP related patents subclasses is presented in the Appendix. It shows the hierarchical structure (Class-subclass), but the hierarchy is somewhat arbitrary. A patent is assigned to several subclasses, the examiner decide the original reference (main classification) and cross-references. This allows exploration of the technological structure with co-classification<sup>20</sup>.

Here the meaning of co-classification should be interpreted with care.

1. A patent contains few classes. They exist as a complementary subset to constitute the patent.
2. Non-exclusive classification allows a technique classified into several similar classes.

Therefore co-classification means either similarity or complementarity.

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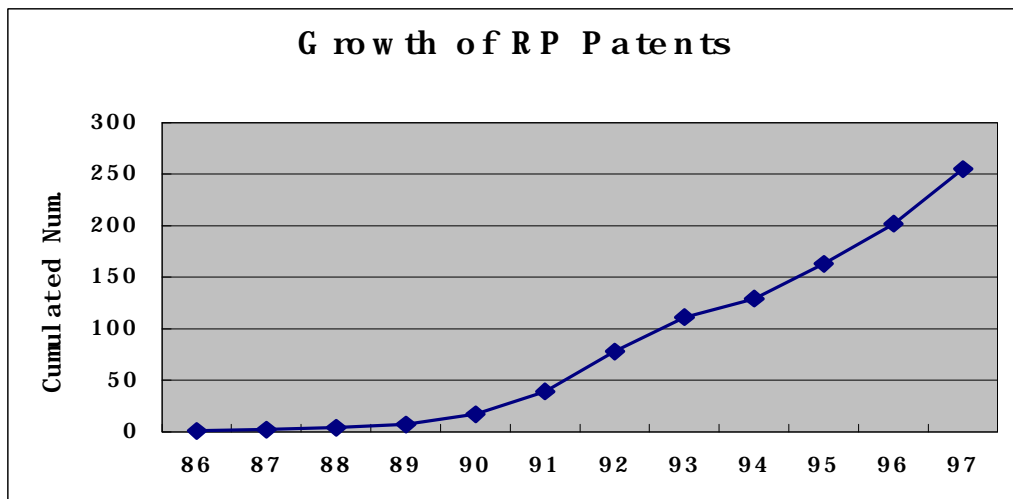
<sup>19</sup> Jacobs et al (1993) First experience in the use of stereolithography in medicine, Proceedings of the Fourth International Conference on Rapid Prototyping, June 14-17

<sup>20</sup> The origin of co-classification was a decade ago (Todorov, 1989). Its use with patents was previously done by Fraunhofer colleagues (Grupp, 1994) and very recently implemented by MERIT. Breschi et al. (1998) used proximity based on co-classification to scrutinise how the proximity between technical field affects diversification of firms.

Here, co-classification is used for producing the symmetric proximity matrix. The proximity is the indirect index based on column comparison. It can be improved by weighting each element of column (strength of linkages). If the purpose is to look at knowledge flows, a citation matrix is better. However, co-classification is complementary to citation matrix because it reveals indirect benefit from knowledge flow. As we saw in previous section, similar interfaces (input-output match) induce new vertical linkages.

The births of subclasses, such as 264/401 Stereolithography (SL) and 264/497 Selective laser sintering (SLS), is prominent and reflects RP technology. RP systems based on the two methods occupy about half of the world market (Wohlers, 1998).

The co-classification matrix on 16 classes related to RP is built. An intertemporal comparison based on 81-85 period and 91-95 period is implemented. The reason for choosing these periods is to see ex-ante and ex-post of the co-classification map. The growth of RP has been continuously increasing since middle of the 80's (See Figure 8).



**Figure 8 Growth of RP patents: Source, Chatham Research database 1998 version**

The 91-95 class level map shows no significant change from the 81-85 period. The dynamics are only caught by subclass mapping, which is presented in the next section.

However, at the subclass level, the change is evident. Two subclass maps are presented in the 3D figure.<sup>21</sup> The consistency between subclasses and the class is shown below. Three subclasses, 264/308, 264/401, and 264/497, are higher combinations with other classes, thus shows low correlation values with the co-classification pattern of class.

<sup>21</sup> SPSS V7.0 Multi-Dimensional Scaling, proximity is recalculated on column cosine (See Breschi et al, 1998)

When we see sudden differences from the general class pattern, subclasses 264/401 and 264/497 are closely linked to co-classification with classes (156) and (250). The meaning is a chemical reaction with radiation diffusing into shaping artefacts. (for definition of classes, see Appendix). In general, the new technology has an intense information interface (345), (364). Sintering technology 264/497 shows an obvious tendency toward laser as heating (219) and metal powder (419). 308<sup>22</sup>, 401 497 are process subclasses they are more intensively linked to product class (425: apparatus for plastic earthenware), which implies that mechanisation occurs.

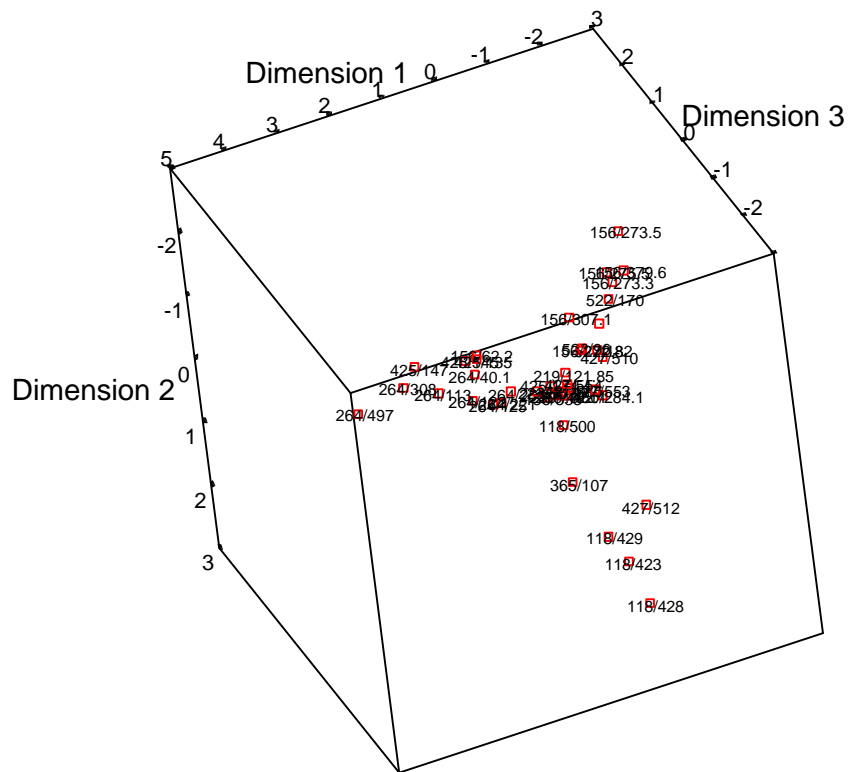
### **Inter-temporal Subclass Maps**

The intertemporal map of RP subclasses presented below (Figures 9, 10), both have moderate distortions by compressing dimension (stress = .17055, .17302 each)

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<sup>22</sup> The subclass 264/308, which is solidification with sequential charging is not a new class but most of them are RP patents

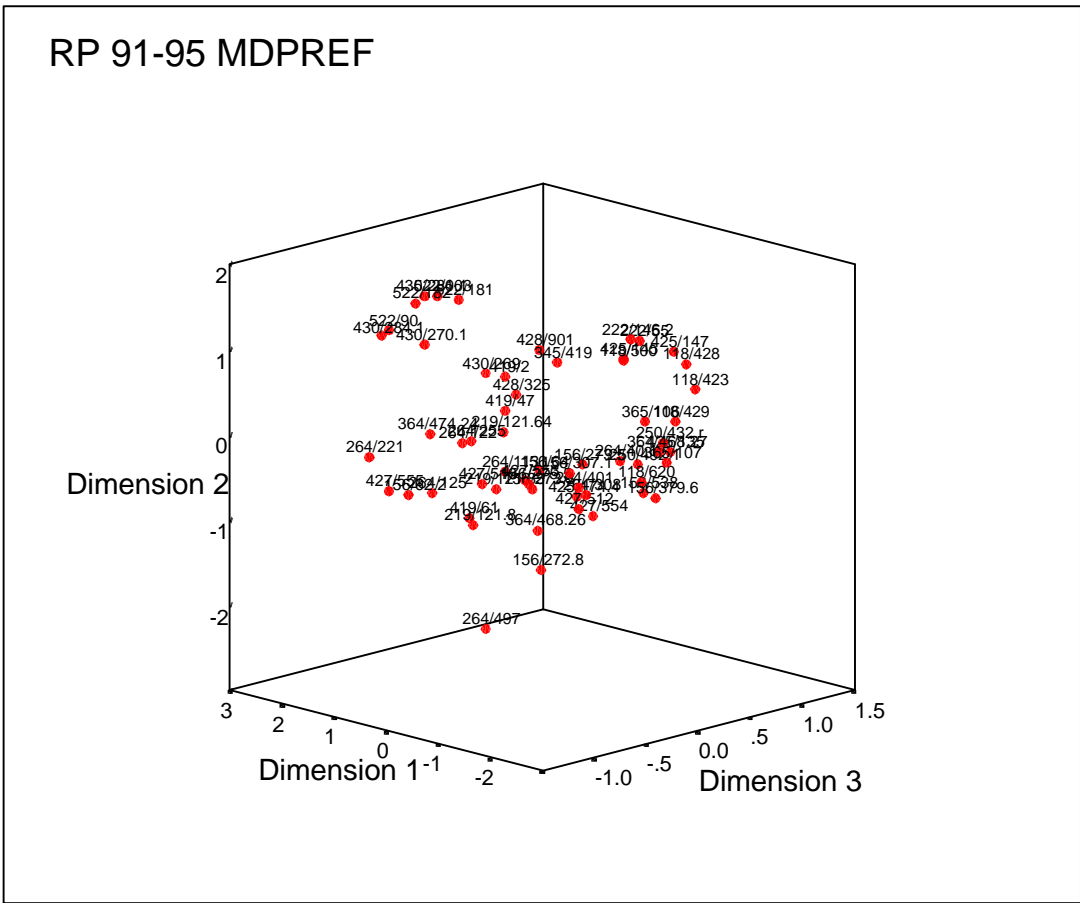
## RP 81-85



**Figure 9 RP subclasses before active development: mapping of 81-85 period**

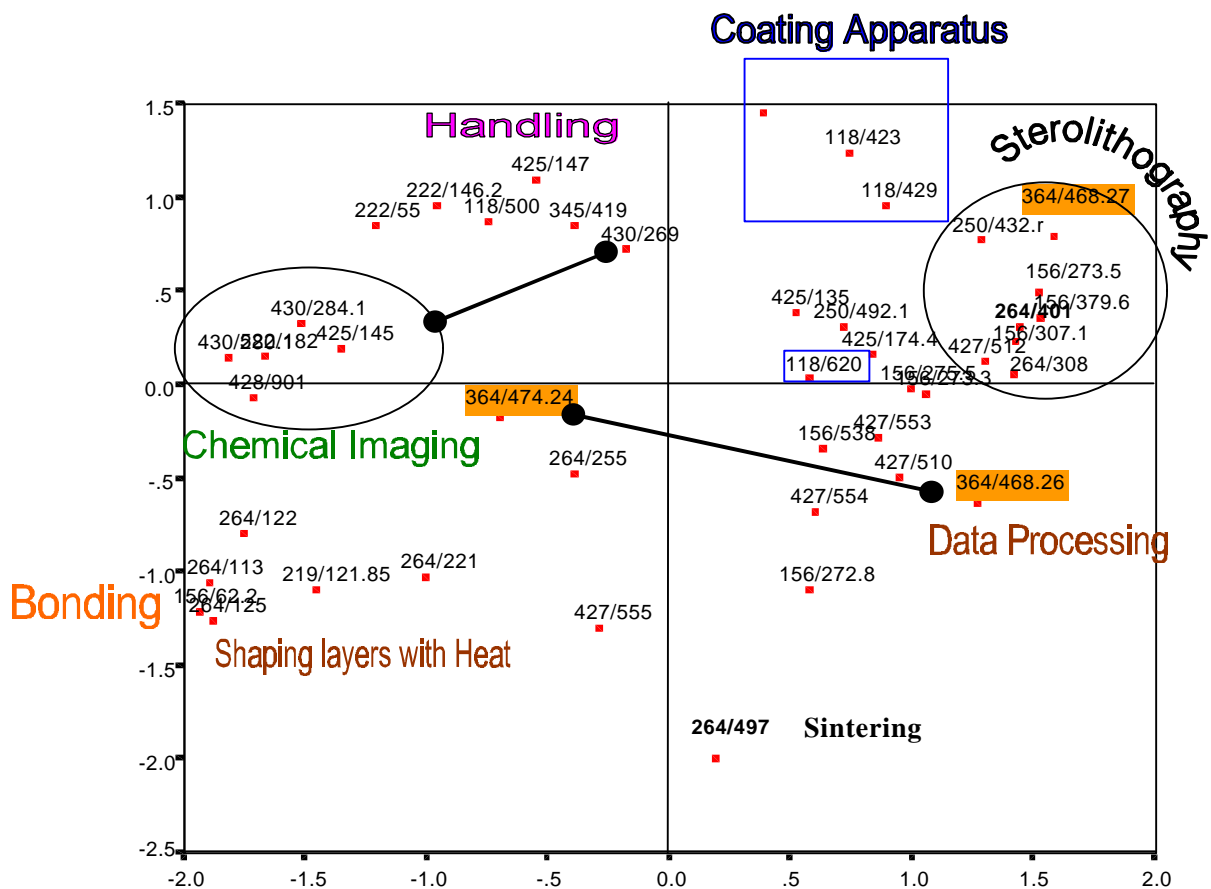
Figure 9 shows each class has a coherent class and well-developed wings of classes.

The wings of 118, 156 and 264 classes do not join with each other, which indicates they were relatively independent before the birth of RP technology.



**Figure 10 RP subclasses after active development of RP: mapping of 91-95 period**

Figure 10 shows more intense intercourse between classes. The independent wings are disappeared with emerging technology (Rapid Prototyping) because of intense combination. Particularly 156: Chemical Manufacturing class and 264: Shaping Non-metal Articles are widely spreading over the map. Apparatus technologies show relatively collective pattern. 118, 425 and 222 are congregating in a corner. This implies the novelty in RP machine mechanism is not so high with regard to activities on the map. For interpretation two-dimensional map on 91-95 is presented below. The axis has no meaning and the positions are relative.



**Figure 11 Explanation of 91-95 RP Subclass Map**

In general, relatively traditional technology is on the left side, and apparatus is in the upper half. Chemical imaging is developed to special subclass 430/269. 118/620 Coating apparatus with radiant energy is the key subclass that links to other subclasses in 156 and 264 in the 81-85 map. Here the position of 118/620 also shows the specific direction. Close to 118/620, a subclass of apparatus for chemical manufacturing (156/538) locates. Software application that deals with the workpiece of manufacturing (364/468.24) which includes NC programming specialised into area rapid prototyping (364/468.26) and stereolithography (364/468.28). Many patents of 427/510 and 427/555 (Coating process with radiant energy to polymerise selected portion) were primarily assigned to the electronic circuit industry.

The handling domain shows a proximity between different apparatus because of their common character of material control. 156/378.6 (radiation mechanism) is apart from the group and belongs to the stereolithography cluster.

**How engineering representation interprets the proximity of technologies?**

The validity of the engineering interpretation is confirmed through a simple linear regression on sample data<sup>23</sup>. The sample is 124 randomly selected co-classification of RP patent subclasses. In the regression, the dependent variable is co-classification intensity, and the independents are dummy variables. There are nine independent dummies that indicate equivalence between two subclasses: Mi (Material Input), Mo (Artefact Output), MiH (Material Input Hierarchically), MoH (Material-Artefact Output Hierarchically), Ei (Energy Input), EiH (Energy Input Hierarchically), ActEtc (Activity etc.), T (Tool), and DI (Data Interface). Energy output linkage does not exist in the sample. For example, if there is similarity in material input, Mi dummy indicates one. To remove collinearity, backward elimination is implemented. Next table shows variables that have the explanatory power and a positive effect on co-classification density. In the RP technology field, energy input, material input and material output similarities are extremely significant (1% level). This is RP technology specific The significance of these variables would vary according to characteristics of technology fields.

Data Period	81-85			91-95				77-98		
Adjusted R_sqr	0.463			0.472				0.516		
Variables*	EiH	Mi	Mo	MiH	EiH	Mi	Mo	EiH	Mi	Mo
Coefficient (E-02)	1.6	4.4	4.8	2.1	4.4	12.3	8.0	3.6	9.9	7.3
Significance	0.006	0.00	0.00	0.054	0.002	0.00	0.00	.001	.00	.00

**Table 1 Validity of Engineering Representation**

\* Constant term is not presented in the table.

Mi: Material & Data Input Similarity, Mo: Material & Data Output Similarity, MiH: Material Input Similarity Hierarchically, EiH: Energy Input Similarity Hierarchically

We can see the engineering presentation is more coherent with 91-95 as we can see higher adjusted R square value. In some sense, the engineering representation indicates future direction of co-classification pattern.

The interpretation of RP related patent classes appear in the Appendix. The main class is "Shaping" (264). Shaping is a technique that transforms physical material into an article

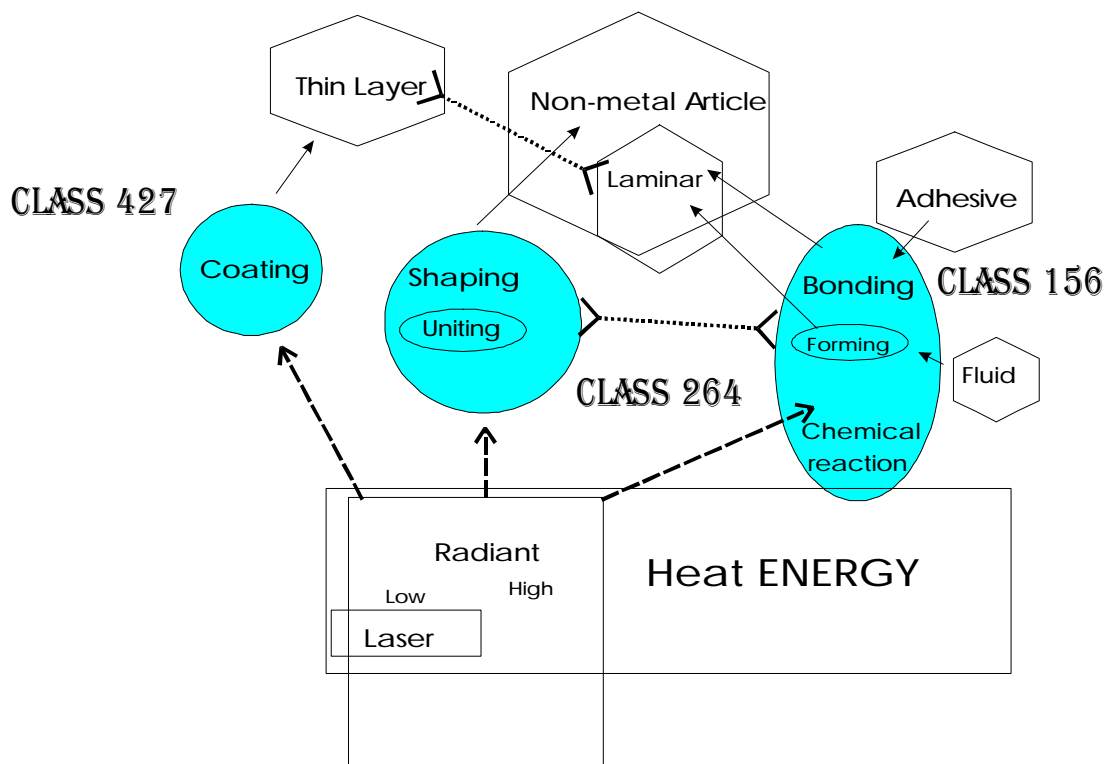
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<sup>23</sup> Engineering representation explains co-classification poorly in terms of Adjusted R square value (0.516), but it is because independent variables are not sophisticated enough to differentiate various level of linkages (only binary values). Unexplained residual is due to complementary side of co-classification because engineering representation

consistent to reference value. Shaping an article is done in three ways, additive deposition, subtractive (cutting), and deformation (Burns, 1993). Fluid material - plastic material - rigid solid has a form of material existence. Transformation of phase is the most common technical activity. Coating and shaping can be similar under certain technological configurations. The coating process making thin layer is not used for producing certain thickness. Accumulated coating to produce 3D article is a combination of coating and shaping by extension of the coating. This is Chemical manufacturing in 156/272.2 family - sequential layer building technology.

One interesting finding from the disclosure of co-classified subclasses is that:

1. In Figure 12, a sub-activity of "shaping" is "uniting", which is equivalent to "bonding". Conversely in the "bonding " class, "forming" that is equivalent to "shaping" exists as a sub-activity. Therefore a similar activity has different hierarchical orders in different classes.
2. The proximity of the process significantly increases when artefacts match (output- laminar and input energy -radiation, which is demonstrated on the above table). The suggested assumption is confirmed that transformation direction of IME attributes is important in proximity.
3. When a new process is highly linked to another process already associated with the apparatus, this implies that high opportunity of mechanisation is generated.



**Figure 12 Similarity between activities through in-out artefacts**

Similarity between activities can be realised with linkages to sophisticated apparatus. In this respect, co-classification between process and product is the most prominent figure. A third of patents in coating apparatus (118) have also a classification of coating process (427) simultaneously. Half of class of apparatus for plastic and earthenware (425) is associated with non-metallic shaping (264).

### **Some Suggestions for the Interface to Modelling**

The aim of engineering representation is two-fold. One is the interpretation of proximity of technology as displayed above. The other is to provide intermediate representation that can connect the Ontology database, the Patent system, and the Leontieff Input-Output matrix. As discussed above, technology structure is not in any strict hierarchical order. Hierarchy can be seen as a specific form of network where a node has various nexus but a subjective nodes only has access to a high level node. Thus network is a general structure that can be used to express technological structure. For modelling asymmetry, a directed graph is a good candidate<sup>24</sup>. A possible solution is programming artificial intelligence that mimics a localised search with

<sup>24</sup> The author (Hwang, 1997) prefers to use the Stochastic Petri Net that is compatible with the Markov random field

regard to service function. Service function gives different weight to network linkage so search paths differ by situation.

Percolation theory (David and Foray, 1994; Cohendet, 1998) indicates different preference or acceptance of the individual. It has actors in network nodes and each actor chooses a phase (or technology) influenced by neighbouring actors. The probability of an actor  $i$ 's choice being affected by another actor  $j$ 's is  $PiPe(i,j)$ , and where  $Pi$  indicates  $i$  actor's propensity to accept others' decision (receptivity) and  $Pe$  is the connectivity between them. This means that the infection is a function of individual preference and the strength of influential connection. A large portion of the probability  $Pi$  can be explained with technological proximity. Although the modelling is designed to simulate actors' decision of adoption under the influence of a neighbouring group, the neighbouring effect and threshold level for transition are compatible with knowledge searching and flow context<sup>25</sup>. The percolation model can be used as a simulation of actors' evaluations of technological proximity.

The growth of technological knowledge can be decomposed into demand factor and knowledge flow from neighbouring technological fields. With regard to knowledge flow, a citation matrix can yield useful information on knowledge growth. If we apply the Gozinto theorem<sup>26</sup> to the citation matrix of patent classes, potential growth of classes by technology input can be evaluated. When considering the non-exclusive nature of knowledge and the dynamic interface with other dimensions<sup>27</sup>, a simulation on a stochastic graph is preferable. Some potential knowledge flow can be evaluated from the co-classification matrix, as can be seen from previous mappings as well as the knowledge input matrix obtained from the citation analysis. How proximity leads to combination should be analysed through investigation of the integrated analysis of knowledge and product flow. However, as seen in the case of pattern and mould, the use of the Leontieff table is limited because it is not sufficiently subtle to differentiate pattern and mould.

## Conclusion

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and is much more flexible.

<sup>25</sup> Pavitt indicated that Percolation theory is useful to figure knowledge diffusion.

<sup>26</sup> This is equivalent to Leontieff's inverse matrix and the inverse matrix of Markov absorption. In the Leontieff (**Quesnay**) table, consumer demand is the absorptive domain. Here, each class in turn is the absorptive domain. For a paper on measuring knowledge influence, see Rousseau (1987).

<sup>27</sup> When the value exceed the threshold it can change input/output ratios

As discussed in the theory section, technology structure is quasi-hierarchical. The flexibility of a quasi-hierarchy allows diverse linkages amongst technical species. Increasing diversity of technology is pictured as the development of complex linkages in inter-temporal maps, and these linkages (co-classification) have been explained using the engineering representation. Also we identified that the same linkages be used to in understanding the technological background of RP diffusion. The representation does not improve the precision of proximity measure. However, it enhances understanding and can be used for artificial intelligence that simulates technological evolution.

The limitation of this paper is the lack of explanations about diverse service functions, which are more sensitive to social and cultural values. Problem-Social group-Solution network (Pinch and Bijker, 1987) is not presented in this paper. However, stochastic graph theory can be used for the problem-solution network, and it can be connected to a network of technology proximity. The extension of modelling should include organisational and economic aspects. To throw light on how technological proximity affects firm boundaries, further effort is needed. Organisational innovation, such as the shift from craft to factory, also demands a micro-Leontieff table (Leijonhufvud, 1986; Andersen, 1997). Therefore we should wait until the ontology and micro-Leontieff table are completed.

Although Callon insists a blurred boundary between social actors and subjective techniques, Gelsing (1989) identifies four types of network. He differentiates the supplier-user network from the vertical product chain (also Giles' filières from knowledge network). By the same token, we maintain that the social entities, such as economic and cultural values, should be differentiated from technological determinants to highlight interactions within technological factors, though the values will be integrated to the same technology network at a later stage.

Finally, the micro-case study on evolution of RP technology implies that this line of research helps the in depth study of evolutionary economics in the following respects:

- Technology proximity helps us to examine how cumulative technological knowledge defines different preferences on technological choices.
- Technological opportunity is not the number of all combination cases, but is more likely to occur around the current combination frontier.

The ultimate tool for technological structure would be the ontology database that can translate individual patent and patent manual automatically. Using stochastic graph, simulation, and empirical data, evolutionary economics of technology can simulate some of the real processes.

## References

- Andersen, E.S. (1994) *Evolutionary Economic: Post-Schumpeterian Contributions*, Pinter
- Bahdi, D. and A. Politi (1997) *Complexity: hierarchical structures and scaling in physics*, Cambridge Univ Press
- Basalla, G.(1988), *The Evolution of Technology*, Cambridge Univ. Press, Cambridge
- Boulding, K. (1978) *Ecodynamics: A New Theory of Societal Evolution*, Sage Publisher
- Breschi, S., Lsoni, F. and Malerba, F. (1998) Knowledge Proximity and Technological Diversification, *DRUID 1998 summer conference*
- Burns, M. (1993) *Automated Fabrication*, PTR Prentice Hall
- Burt, R. and D.S. Carlton (1995) Another Look at the Network Boundaries on American Markets, *American Journal of Sociology* 95, 723-753
- Callon, M., John Law, and Arie Rip (1986) *Mapping the dynamics of science and technology*
- Callon, M.(1993), Variety and Irreversibility in Networks of Technique Conception and Adoption, in Freeman and Foray (ed.), *Technology and the Wealth of Nations: the dynamics of constructed advantage*.
- Clark, K.B.(1985), The Interaction of Design Hierarchies and Market Concepts in Technological Evolution, *Research Policy* 14, No.5, pp.235-251
- Cohen, W.M. and Levinthal D.A. (1989) Innovation and Learning: The Two faces of R&D, *Economic Journal* 100,
- Cohendet. P (1998) Network, Interactions between economic Agents and Irreversibilities: the Case of the Choice among Competing Technologies, In Cohendet, P. and P. Llerna, H. Stahn, and G. Umbhauer (ed.) *The Economics of Network*, Springer
- Constant, E. W. (1980), *The Origin of Turbojet Revolution*, The Johns-Hopkins University Press, Baltimore
- Cunningham, S. (1996) *The Content Evaluation of British Scientific Research*, Dphil Thesis, SPRU
- Doreian, P. (1988) Equivalence in a Social Network, *Journal of Mathematical Sociology* 13

- Ferguson, E.S. (1992) *Engineering and the Mind's Eye*, MIT Press
- Fleck, J.(1998), Artefact-Activity: The co-evolution of artefact, knowledge and organisation in technological innovation, in Ziman Ed., *Technological Innovation as an Evolutionary Process*, Cambridge University Press
- Gorman, M.E. (1997) Mind in the World: Cognition and Practice in the Invention of the Telephone, *Social Studies of Science* 27, 583-624
- Granberg. A (1995) Mapping an Evolving Technology Cluster: The Composition and Structure of Factory Automation, in Carlsson, B. (ed.) *Technology System and Economic Performance: The Case of Factory Automation*, Dordrecht: Kluwer
- Gelsing, L. (1989) Knowledge Network, Industrial Flexibility, and Innovation, in Borum and Kristensen (ed.) *Technological Innovation and Organizational Change -Danish Patterns of Knowledge, Networks and Culture*, Copenhagen: Danish Social Science Research Council
- Granstrand, O. (1994) Technological, Technical and Economic Dynamics: Toward a Systems Analysis Framework, O. Granstrand (ed.) *Economics of Technology*, Amsterdam: Elsevier
- Gruber, T.R. (1994), A Translation Approach to Portable Ontology Specifications, *Technical Report KSL 92-71*, Stanford University
- Grupp, H. (1994), The Dynamics of Science-Based Innovation Reconsidered: Cognitive Models and Statistical Findings, in O. Granstrand (ed.) *Economics of Technology*, Amsterdam: Elsevier
- Hwang, J. (1997) *Development of Network Influence Index for Co-word Map*, unpublished MS thesis, Seoul National University
- Fleck, J.(1998), Artefact-Activity: The co-evolution of artefact, knowledge and organisation in technological innovation, in Ziman Ed., *Technological Innovation as an Evolutionary Process*, Cambridge University Press
- Freeman, C. Clark, J. and Soete, L. (1982) *Unemployment and Technical Innovation: A Study of Longwaves and Economic Development*, London, Pinter
- Helpman, E. and Trajtenberg, M. (1994) One Step Backward, Two Forward: General Purpose Technologies and Long-term Growth, *Center for Economic Policy Research Publication 398*
- Henderson, R.and Clark, K. (1990) Architectural Innovations: The Reconfiguration of Existing Products and the Failure of Established Firms, *Administrative Science Quarterly* 35, 9-30
- Hughes, T. (1982) *Network of Power: Electrification in Western Society 1880-1930*, The John Hopkins Univ Press
- Jaffe, A. (1986) Technological Opportunity and Spillovers in R&D: Evidence from Firm's Patents, Profits and Market Value, *American Economic Review* 76, pp.984-1001
- Leijonhufvud, A. (1986) Capitalism and the Factory System in R. N. Langlois (ed.) *Economics as a Process*, Cambridge Univ Press

- Marple, D.L. (1961), The Decision of Engineering Design, *IEEE Transactions of Engineering Management*, Vol.2, pp.55-71
- McKelvy, M. (1994) Evolutionary Innovation: Early Use of Genetic Engineering, PhD dissertation, Department of Technology and Social Change, Linköping University
- Nelson, R.R. and Winter, S.G. (1977), In Search of Useful Theory of Innovation, *Research Policy* 5, pp.36-76
- Nightingale, P. (1998) A Cognitive Model of Innovation, *Research Policy* 27, Vol. 7, 689-710
- Noyons, E.C.M. and van Raan, A. F. J. (1998) Advanced Mapping of Science and Technology , *Scientometrics* 41, 61-67
- Lotka, A.J. (1926) The Frequency Distribution of Scientific Productivity, *Journal of the Washington Academy of Science* 16, No12, pp317-323
- Merton, R.K. (1968) The Matthew Effect in Science, *Science* 159, January 5, pp 56-63
- Patel, P. and K. Pavitt (1997) The technological competencies of the world's largest firms: complex and path-dependent, but not much variety, *Research Policy* 26, 141-156
- Peter, H.P.F. and A.F.J. van Raan (1993) Co-word-based Science Maps of Chemical Engineering, Part I : Representations by direct multidimensional scaling, *Research Policy* 22, pp 23-45
- Pinch, T. and W.E. Bijker (1987) The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other, in Bijker, Hughes, and Pinch (ed.) *The Social Construction of Technological System*, Cambridge MA: MIT Press
- de Solla Price, D. (1984) The Science/ Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation, *Research Policy* 13, 3-20
- Rosenberg, N. (1976), *Perspectives on Technology*, Cambridge Univ. Press
- Rousseau, R. (1987) The Gozinto Theorem: Using Citation to Determine Influences on a Scientific Publication, *Scientometrics* 11, 217-229
- Saviotti, P. and Metcalfe, J. (1984), "A theoretic approach to the construction of technological output indicators", *Research Policy* 13, pp. 141-151
- Saviotti, P. (1996) *Technological Evolution, Variety, and the Economy*, Edward Elgar
- Sahal, D. (1976) The Generalized Distance Measure of Technology, *Technological Forecasting and Social Change* 9, 289-300
- Sahal, D. (1985) Foundations of Technometrics, *Technological Forecasting and Social Change* 27, pp 1-37

Scherer, F.M. (1982) Inter-Industry Technology Flows in the United States, *Research Policy* 11, 227-245

Schmookler, J. (1966) *Invention and Economic Growth*, Harvard Univ Press, Cambridge MA

Stirling, A. (1998) On the Economics and Measurement of Diversity, *SPRU Electronic Working Paper* 28

Vincenti, W. G. (1990) *What Engineers Know and How They Know It*, The Johns-Hopkins University Press, London

Weitzman, M. (1992) On Diversity, *Quarterly Journal of Economics* 107

Wohlers, T. (1998) *Rapid Prototyping and Tooling State of the Industry: 1998 Worldwide Progress Report*