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Thriving in the Innovation Economy through Collaborations of Government, Universities, and Industry

Abstract: Thriving in the innovation economy demands a different approach to policy and programs. It requires a higher degree of collaboration between government, universities, and industry, and the establishment of regional innovation networks to generate new jobs and wealth. It requires economic development policies that will facilitate the movement of intellectual property and human capital between academia, industry, and our Federal labs and institutions. Further, it needs to be sustainable. Thriving in the innovation economy is a journey, not a one-time event. It is the creation of a persistent regional collective intelligence that continuously produces the innovations which are the foundation of a lasting competitive advantage. This paper presents a new approach using Innovation Network Mapping, and the concept of an Innovation Genotype™, to accomplish these objectives.

This is the companion paper to the February 28, 2017 presentation at the National Academies of Sciences, Engineering, and Medicine – Government-University-Industry Research Roundtable.

Contents

Introduction

This paper will introduce the concept that the innovation economy is fueled by collective human intelligence. Intelligence that acquires and applies knowledge and skills to create the insights, inventions, and innovations that change human behaviors, and create the value that leads to wealth and prosperity. We will propose that the ecosystem supporting the innovation economy can be thought of as a collection of networks of networks, in which, creative people from government, academia, and industry engage in the tacit-explicit dialogue to generate new knowledge and skills. This model of the ecosystem as a collection of networks of networks, will enable the application of network science, mathematics, and tools to visualize, characterize, and quantify the ecosystem. In turn, this knowledge will enable development of better economic policy and programs at the level of the individual, group, organization, and region. We will propose several mechanisms to increase collaboration and knowledge exchange, and finally suggest that the ultimate goal is to create a sustainable regional culture of innovation.

The Innovation Economy

We have entered an economic era where our security and prosperity are ever more dependent upon innovation. Where the classic economic factors are still necessary, but not sufficient to survive and thrive. Where cycles of Schumpeterian creative destruction are more frequent than in any other time in history.

The source of the insights, inventions, and innovations that fuel these cycles of creative destruction is human intelligence – our ability to acquire and apply knowledge and skills[1]. More precisely, in today's complex world it is through the "collective intelligence[2]" of a network of creative people who produce the insights, inventions, and innovations that change our behaviors, create value in society, and fuel economic growth and prosperity.

It is in this context that Paul Romer's claims are important, "Ultimately, all increases in standards of living can be traced to discoveries of more valuable arrangements for the things in the earth's crust and atmosphere." He concludes, "The fundamental challenge in economic growth is to find these new arrangements." And, "No amount of savings and investment, no policy of macroeconomic fine-tuning, no set of tax and spending incentives can generate sustained economic growth unless it is accompanied by the countless large and small discoveries that are required to create more value from a fixed set of natural resources. These discoveries are the product of a complicated set of market and nonmarket institutions that constitute what has been called a national innovation system[3]."

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[1] Google online dictionary definition of Intelligence

[2] "Collective Intelligence: Mankind's Emerging World in Cyberspace", by Pierre Levy, Helix Books, 1999.

[3] Romer, Paul M. 1993. "Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards", (Brookings Papers on Economic Activity, 1993, No. 2)

Like explorers searching for precious gemstones, we must search for those innovations that fuel economic growth. And just as the energetic processes, deep within the earth, combine basic elements to form a gemstone, that is brought to the surface through processes of faulting, folding and uplift – so too, the creative processes, deep within the human mind, form the novel, nonobvious and valuable combinations of knowledge and skills, that are brought to the surface through the process of innovation. And as geologists map the surface and substructure of the earth to locate rich deposits of gemstones, we will use network science to help us map the innovation networks that will yield the richest deposits of collective intelligence.

Collective Intelligence the Micro-Foundation of Economic Growth

But what is the underlying process, deep within the human mind, that enables a network of people to acquire and apply knowledge and skills that results in new combinations of greater value to society? Romer defines this process, the "micro-foundation[4]" of economic development – the process in which one person makes their tacit[5] knowledge explicit so that another person can ingest it, and enlarge their own store of tacit knowledge, thereby creating a larger basis set from which to find those new, and more valuable combinations. Nonaka calls this same process the tacit-explicit dialogue[6]. He claims it is the fundamental process of organizational knowledge creation.

So given a collection of N people how many tacit-explicit dialogues, between two or more members, are possible? The answer is given by Reed's Law[7]:

$$\text{Tacit-Explicit Dialogues} = 2^N - N - 1$$

The number of possible tacit-explicit dialogues grows exponentially with N. For example, with 3 people there are 4 possible tacit-explicit dialogues. Increase the group to 4 and there are 11 potential dialogues involving two or more members. Double that to 8 members and number jumps to 237. If each member of the group starts off with a slightly different set of tacit knowledge elements, the number of possible novel combinations of knowledge elements becomes enormous. This is why the tacit-explicit dialogue is a powerful micro-foundation for collective intelligence and thus economic growth.

But not all combinations are equally valuable. It is those combinations that we recognize as truly creative that are valued the most. Arthur Koestler studied these creative combinations in art, literature, humor, science and technology, and found a common basis. The most creative combinations occur when someone associates two planes of thought that are normally disjoint, or orthogonal to each other, and discovers

[4] Romer, Paul M., "Human Capital and Knowledge", Paul Romer's website, October 7, 2015.
[5] Polanyi, Michael, "The Tacit Dimension", University of Chicago Press, 1966.
[6] "Managing Flow – A Process Theory of the Knowledge-Based Firm" and "The Knowledge-Creating Company" by Ikujiro Nonaka et al.
[7] Wikipedia Reed's law.

something of value at the intersection. He named this creative process "bisociation" [8]. These combinations are most likely to produce radical or disruptive innovations that change society and the economic landscape. These are the paradigm shifts in science[9] and technology[10] that enable cycles of creative destruction.

The lesson for economic development is that in addition to the neoclassical macro-economic policies, we need policies, programs, and mechanisms to increase tacit-explicit dialogues in our economy. We need policies and mechanisms to expose the members of our organizations and enterprises to alternative planes of thought, new paradigms and mental models.

Limits to Collective Intelligence

There are limits to collective intelligence based upon the limits of the tacit-explicit dialogue. The first limit is all N people must be members of the same network, that is, they are connected to one another by some mechanism for communication and collaboration. Second, the tacit-explicit dialogue is a social phenomenon that depends upon trust between the participants. People willingly dialogue only with those they trust. Third, participants must be motivated to engage in dialogue, preferably intrinsically motivated. It is best if all participants in the dialogue are passionate about a common problem or opportunity. Fourth, externalities like geography, building structure, financial policies, reporting structure, etc., can and will reduce the actual number of dialogues. Finally, there is the fundamental limit of our human capacity for intense bilateral dialogue. Even using today's social media platforms that eliminate most of the barriers, studies find that participants with thousands of "friends" in their social media networks rarely carry on intense bidirectional conversations with more than half a dozen people[11]. Fortunately, even with only six participants, there are according to Reed's Law 57 different tacit-explicit dialogues possible.

Innovation Ecosystems as Innovation Networks

Next we will explore the innovation economy that is fueled by the insights, inventions, and innovations of our collective intelligence. We will look at the innovation ecosystem that makes possible the innovation economy, and show that it can be thought of as a collection of innovation networks. Doing so will enable us to both tie back to the fundamental foundation of economic growth, the tacit-explicit dialogue, and collective

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[8] "The Act of Creation", by Arthur Koestler, Hutchinson & Co., 1964.
[9] "The Structure of Scientific Revolutions – 50th Anniversary Edition", by Thomas Kuhn, the University of Chicago Press, 2012.
[10] "Future Shock", by Alvin Toffler, Random House, 1970.
[11] "Networks, Crowds, and Markets: Reasoning about a Highly Connected World", by David Easley and Jon Kleinberg, Cambridge University Press, 2010.

intelligence, and introduce network science to generate the models and metrics that we need to guide policy making in the innovation economy.

So what is this ecosystem that supports the innovation economy? By analogy to a biological ecosystem, Jackson defines it as: "… an innovation ecosystem models the economic rather than the energy dynamics of the complex relationships that are formed between actors or entities whose functional goal is to enable technology development and innovation. In this context, the actors would include the material resources (funds, equipment, facilities, etc.) and the human capital (students, faculty, staff, industry researchers, industry representatives, etc.) that make up the institutional entities participating in the ecosystem (e.g. the universities, colleges of engineering, business schools, business firms, venture capitalists (VC), industry university research institutes, federal or industrial supported Centers of Excellence, and state and/or local economic development and business assistance organizations, funding agencies, policy makers, etc.).[12]"

Thus an innovation ecosystem is a set of "complex relationships" between a broad set of "actors or entities". Any collection of actors or entities that are connected through a web of relationships can be modeled as a network. This is important, because a vast body of science, mathematics, and software exists that will allow us visualize, characterize, and measure these networks. This, in turn, will enable us to identify the richest deposits of knowledge and skills to mine for those precious insights, inventions and innovation gemstones.

The Living Systems of Economic Development

James Grier Miller[13] showed that the cell, organ, organism, group, organization, community, society and supranational system all depend upon the same analogous twenty critical subsystems for managing matter, energy and information. His ideas apply equally well to economic development networks, and in particular at the levels of: the individual (organism), group, organization (public or private enterprise), and region (community). And the critical common subsystem that we will focus on at all levels is human intelligence, individual and collective.

The individual's innovation network is created by "ingesting" the knowledge and skills made explicit by others, and codifying it as tacit knowledge in the form of neural networks. These neural networks embody the concepts that an individual can combine in their mind to create new, nonobvious, and valuable combinations. The acquisition and application of knowledge and skills defines human intelligence. A primary mechanism for increasing intelligence is education, hence the importance of the education system in the innovation economy.

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[12] Jackson, Deborah J., "What is an Innovation Ecosystem?", National Science Foundation, 15 March 2011.
[13] Miller, James Greer, "Living Systems", University Press of Colorado, 1995.

Individuals come together to form groups, which have the ability to acquire and apply knowledge and skills at a rate that far exceeds that of the individual. The group's innovation network is the ensemble of its members' individual neural networks. Tacit-explicit dialogues among group members enlarge each individual's tacit knowledge, forming a larger basis set from which to seek novel combinations that resolve a need. The group innovation network is the most basic form of collective intelligence.

An organization's innovation network is a network of group networks, and individuals who work towards larger goals and purposes. Classically, such networks have been organized in a hierarchical topology with individual group networks for product lines, marketing, sales, R&D, finance, HR, etc. Each of these groups connected to each other through the management chain. The degree of connectivity within and between members of these groups will influence the robustness of the internal tacit-explicit dialogue, and thus the organization's collective intelligence[14].

Finally, the innovation network of a regional cluster is a network of organizational networks, which, themselves, are networks of groups and individuals. A cluster has a very broad spectrum of nodes – actors and entities from the underlying innovation ecosystem. As within an organization, the ability for members of a regional cluster to acquire and apply knowledge and skills will be determined, to some extent, by the connectivity between members of the region. A regional cluster is, in some sense, a "society", and its collective intelligence, like that of a society, increases as it evolves to a more connected network topology[15].

So what does this mean for economic development? It means that in addition to classic economic development policies, to thrive in the innovation economy we need to develop an additional comprehensive and coherent set of policies and programs at all four levels: individual, group, organization, and region. We need to understand how the micro-foundational process can be facilitated at every level. Finally, we need to be able to visualize and measure the individual, group, organization, and regional innovation networks to inform our actions and measure success.

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[14] "Diagnosing and Changing Organizational Culture: Based on the Competing Values Framework", by Kim S. Cameron and Robert E. Quinn. Cameron and Quinn have looked at the role of social network topologies in determining organizational culture. Their competing values framework (CVF) characterizes the culture of an organization along two orthogonal axes. One axis measures the organization's propensity for control versus flexibility, the other its degree of internal versus external focus. This results in four cultural archetypes they call: the Clan, Command & Control, Market, and Adhocratic. They claim that, as organizations progress through the four forms from clan to adhocratic, they become progressively more innovative. In an adhocratic organization the tacit-explicit dialogue is more robust and diverse, which enhances the organization's collective intelligence.

[15] "Tribes, Institutions, Markets, Networks: A Framework about Societal Evolution" by David Ronfeldt of RAND Corporation. In his theory of societal evolution Ronfeldt concluded that societies progress through organizational forms beginning with tribal, advancing to institutional, then market, and finally what he calls networked (Cameron's adhocracy). He claims that each successive form incorporates the previous forms, restricting the earlier forms to what they do best, and extending the society's capacity for solving ever more complex problems by the addition of the newer forms.

Mapping Innovation Networks

Next we will explore mapping innovation networks at all four levels to understand how network science can help define and measure the effects of economic policy for the innovation economy.

Mapping innovation networks requires data that reveals the acquisition and application of knowledge and skills – intelligence. There are many types of data that can be used[16], but we will focus on utility patents that reveal how knowledge and skills have been acquired and applied to create new processes, machines, means of manufacture, and compositions of matter. Our justification for this singular focus is based on the work of Paul Romer[17] and his theory of endogenous growth, and the Brookings Institute finding of a strong relationship between a region's prosperity and its ability to generate patents[18].

To understand this relationship between a region's prosperity and its ability to generate quality patents, consider that by federal statute, any person who "invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent.[19]" It is the new and improved processes, machines, means of manufacture, and compositions of matter that are the foundation of scalable products and services, which create jobs and prosperity. Second, the ability to generate patentable inventions reveals the region's strength in science, technology, engineering and math (STEM), which, in turn, has been linked to innovation and economic growth[20]. Third, a study conducted by Harvard Business School and the Stern School of Business in 2016 concluded that a startup's first patent application substantially increases the likelihood of raising venture capital[21]. Obtaining venture capital is important to building an entrepreneurial ecosystem with strong endogenous growth.

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[16] "America's Knowledge Economy: A State-by-State Review", by Brad Fenwick of Elsevier and David Adkins of The Council of State Governments, 2015.

[17] Paul Michael Romer is the Chief Economist and Senior Vice President of the World Bank who is known for his work in the field of economic growth. See, Romer, Paul M. 1993. "Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards", (Brookings Papers on Economic Activity, 1993, No. 2)

[18] The Brookings Institute 2013 report "Patenting Prosperity: Invention and Economic Performance in the United States and its Metropolitan Areas", by Jonathan Rothwell et al

[19] US Patent & Trademark Office.

[20] "STEM Education Key to Innovation and Economic Growth", National Governors Association

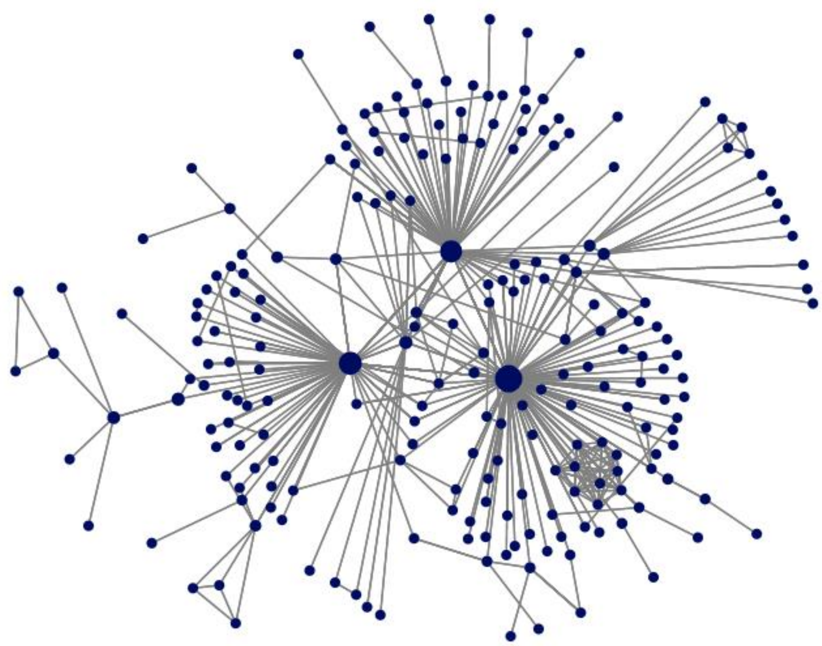
[21] "Do Patents Facilitate Entrepreneur's Access to Venture Capital?" by Joan Farre-Mensa, et al, October 6, 2016.

Regional Innovation Networks

The first network we will examine is the regional-level inter-enterprise collaboration network for the state of Maryland. This network consists of granted patents and published patent applications filed from January 2013 through August 2016, where the assignee organization's address was in the state of Maryland, and one or more inventors lived in Maryland. We insisted that one or more of the inventors reside in Maryland to eliminate the situation where a Maryland organization funded out of state organizations and retained rights to the intellectual property. With these restrictions we found 2,959 inventions.

Next, we selected for inventions that had two or more Maryland organizations as co-assignees. This additional restriction reduced the collection to 277 inventions that indicated collaboration between multiple organizations (private sector, academic, or government enterprises). Finally, these collaborative inventions were generated by 241 unique enterprises located in Maryland.

Figure 1: Maryland's Inter-Enterprise Collaboration Networks



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In the figure above each node indicates a different enterprise, each link indicates that there were one or more inventions on which they collaborated (co-assignees). First, notice there is one very large connected component, color coded in dark blue. The multicolored dyads and one triad in the lower left of the graph are the few inter-enterprise collaborations that were not part of this larger collaborative network.

Next, the diameter of each node was scaled according to its betweenness centrality, a network property that indicates how frequently that enterprise is on the shortest path between any two other randomly chosen organizations in the network. What is striking is that Maryland's inter-enterprise collaboration network is dominated by just 3 of the 241 organizations. Remove any one of these three organizations and the network degrades significantly. Further, these three organizations are interconnected by a small number of organizations in the center of the network. However, each dominant organization has its own set of collaborating organizations, radiating outwardly, that for the most part, are only sparsely connected to each other.

The three dominant organizations are: Johns Hopkins University (top center), University System of Maryland (lower left), and Health and Human Services (lower right)[22]. Maybe we shouldn't be surprised that they are universities and a Federal agency, but there are many universities[23], Federal agencies, and military installations in Maryland, why are these three dominant? What do these three organizations know about inter-enterprise collaboration that the others do not? What policies and practices do they have that enable collaboration, and could they be adopted by others? Why is the connectivity between each dominant organization's individual collaboration networks so sparse, and what innovations could be generated by increasing connectivity between them?

Finally, located between 4 and 5 o'clock in the diagram is a densely connected network of ten organizations. This is the most densely connected set of organizations in the network. Why are they so densely connected? It turns out these ten enterprises, and HHS, are all connected by a single invention focused on predicting survival rates for people with diffuse large B cell lymphoma (DLBCL)[24]. This patent application has 24 inventors and 11 assignees from 5 countries. It is an interesting example of supranational inter-enterprise collaboration to solve an extremely challenging problem. How did eleven organizations across five countries collaborate to acquire and apply all of the requisite knowledge and skills? If this is the future in complex fields such as cancer research, what can we learn from this example that would accelerate solutions for other complex challenges in other domains?

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[22] Note, it is possible to decompose USM and HHS into their individual units, however, it was not an objective of this initial analysis. For HHS, only patents assigned to HHS facilities in Maryland were included.

[23] For example, at the time of this writing there are 55 accredited colleges and universities in the state of Maryland, 12 of which are part of the University System of Maryland. There are 14 military installations and 19 federal agencies in Maryland.

[24] 20150132297 - SURVIVAL PREDICTOR FOR DIFFUSE LARGE B CELL LYMPHOMA

Next, in total there were 2,959 inventions, of which, only 277 had multiple assignees. Why wasn't there more collaboration amongst the assignees of the remaining 2,682 inventions? What can the 90% learn from the 10%? What policies would encourage their collaboration?

Finally, we asked if the degree of inter-enterprise collaboration was a function of the technical domain in which the organizations were innovating. For example do, medical innovations require more collaboration than communications or semiconductor innovations? To answer this question we calculated the Innovation Genotype™, which will be explained later in this paper. The inventions spanned a wide spectrum of technical domains indicating that collaboration was related to the practices of the organizations, and not the technical domains[25].

Mapping inter-enterprise collaboration networks will do several things for economic development policy makers. First, it will reveal the topology of a region's networks, which is indicative of their strengths and weaknesses. Second, it will identify the organizations that can be the source of best-of-breed policies and practices. These organizations are a valuable resource to engage in developing successful regional innovation policies and programs. Third, the maps highlight opportunities to increase connectivity, and hence innovation. For example, what could be done to better connect the collaborators of the three dominant enterprises to each other? What can the collaborators teach the non-collaborating organizations?

Enterprise Innovation Networks

One step down from the region's inter-enterprise network is the innovation network of an individual enterprise. In the figure below we present the innovation network of a sports equipment and apparel company. Each node represents an individual inventor in that company. Each link between two nodes indicates they have co-invented one or more times. For visual clarity we have removed 23 solo inventors that have never invented with another person in the company. The patents and published patent applications spanned a four year period from January 2013 through December 2016, during which 851 inventors, collaborated two or more at a time, to produce 1,188 inventions.

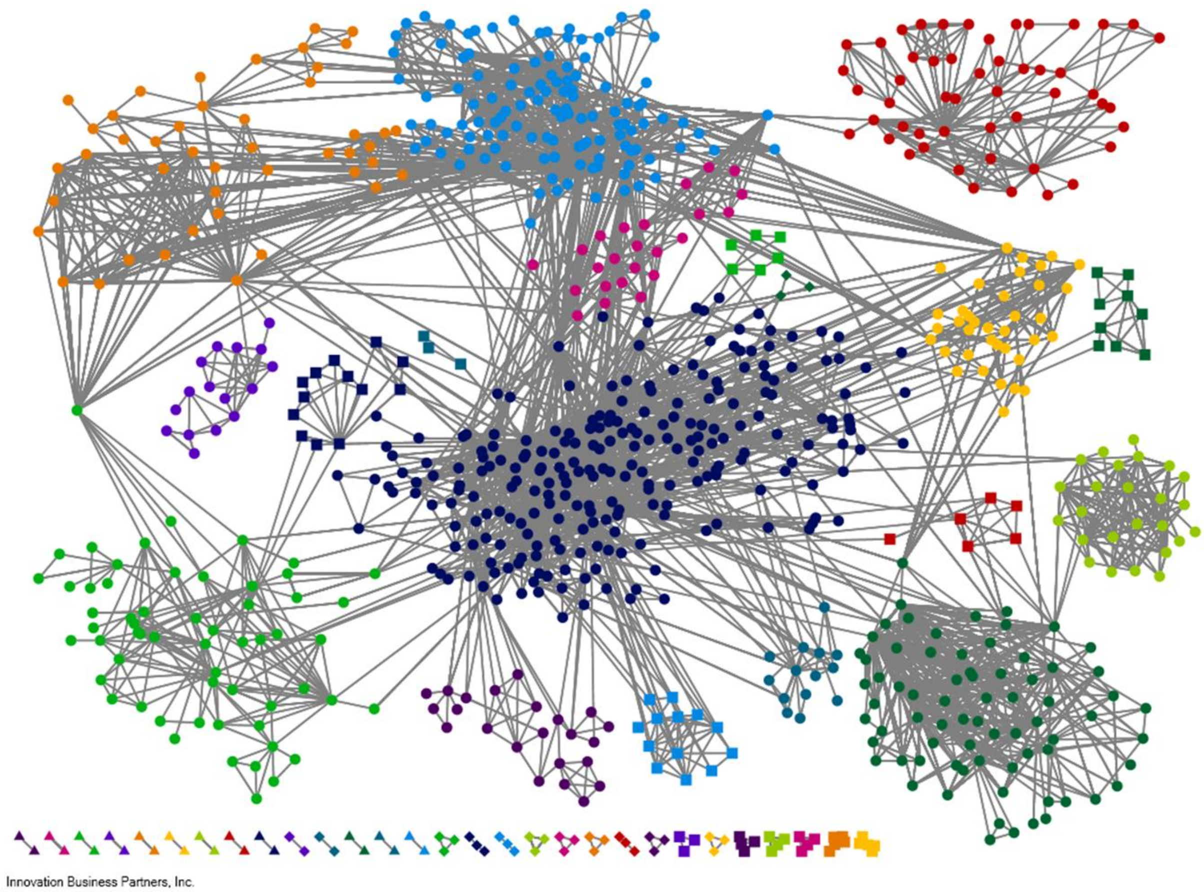
This organization's Innovation Network has a very interesting topology. First, it has multiple clusters, highlighted in different colors. Clusters can be caused by many things, e.g. geography, product focus, organizational reporting structure, etc. Second, if we calculate the connected components[26] we find 30 connected groups ranging in size from two inventors to 771. That largest connected component of 771 represents 88% of all inventors in the organization. This is important because knowledge propagates more

[25] See the appendix for the Maryland Inter-Enterprise Collaboration Innovation Genotype.

[26] To calculate a connected component one starts with a randomly chosen inventor and identifies all of the inventors he/she has invented with. Next, for all of these one degree distant inventors, you identify everyone they have invented with, and so on, until you run out of connections.

easily within a connected component, and the larger the connected component the easier knowledge is shared across the organization.

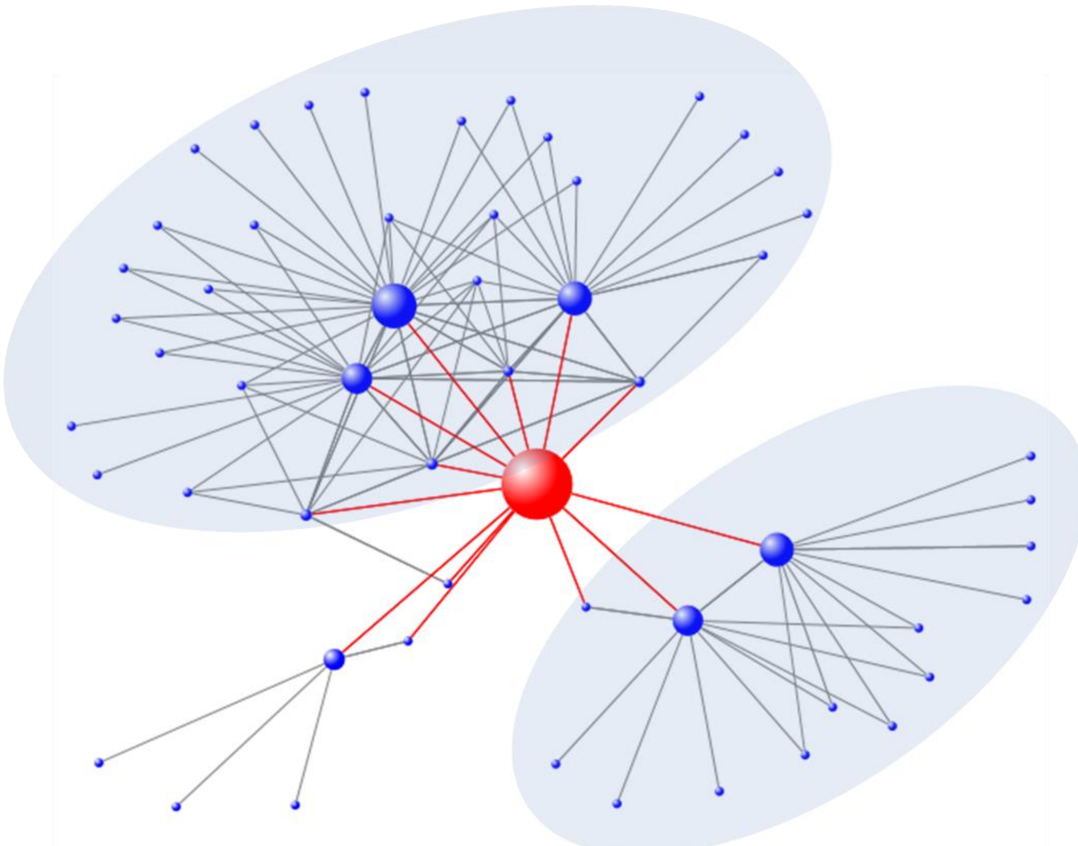
Figure 2: Example of an Individual Organization’s Innovation Network



While, in our experience, 88% is a good number for the largest connected component, note that in this network several of the major clusters in the largest connected component are only connected by a few “trusted Bridgers”. Should these people leave, the connected component would break apart, and the average path length between inventors increase, thus decreasing, slowing, or disrupting the flow of knowledge.

The figure below illustrates an extreme example of a trusted Bridger, and the impact their departure can have. This particular military organization that has two distinct technology groups that are located a few miles apart in different buildings on the same base. The larger upper group, light blue oval at 10 o’clock, designs and builds weapons systems. The smaller lower group, light blue oval at 5 o’clock, develops the energetic compositions of matter that the weapons systems deliver. For over forty years, the inventor highlighted in red, bridged the two groups, and was a co-inventor on every invention that involved inventors from both groups. After this inventor left the organization there was never again an invention that involved inventors from both groups. What knowledge did this inventor have, and what behaviors did the inventor practice to help the organization find the inventions at the intersections? What innovation policies could the organization have created to facilitate this inventor and others to perform the bridging function? How could management have used periodic network mapping to identify this single point of failure and train a replacement in time?

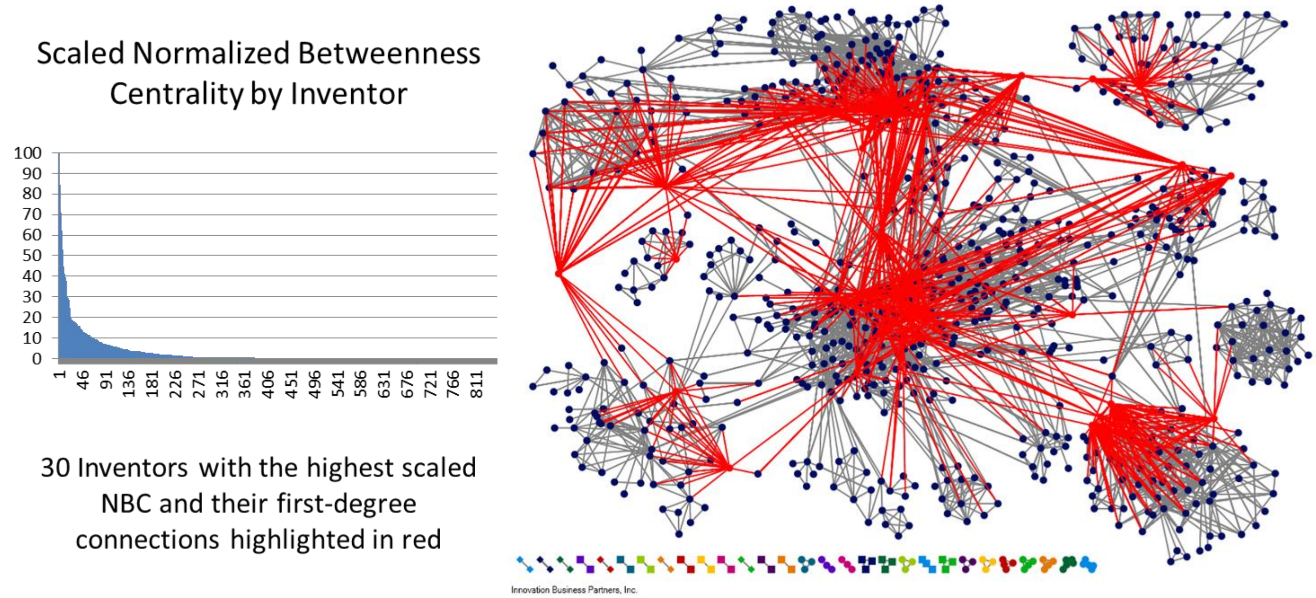
Figure 3: The Importance of Trusted Bridgers



The Innovation Backbone™

Enterprise level networks reveal another interesting phenomenon which we call the Innovation Backbone™. First, invention is a social process, people share ideas with those they trust. Further, in a social network trust decreases dramatically with the degrees of separation between any two randomly chosen inventors. Next, betweenness centrality is a network measure of how frequently an inventor is on the shortest path between any two other randomly chosen inventors, and the shorter the path the higher the trust. If we calculate the betweenness centrality of all inventors, normalize it for the size of the network, and scale it from 0 to 100 we find that a small fraction, usually less than 10% of the inventor population, own almost all of the betweenness centrality – they form the high-trust backbone that connects the network, drives innovation, and facilitates the propagation of knowledge in an organization.

Figure 4: Example of an Innovation Backbone



In the figure above the normalized betweenness centrality (NBC), scaled from 0-100, is presented in the blue barchart, left side of the figure. The y-axis is the inventor's NBC value, the x-axis lists the 851 inventors in descending order. Note the exponential decay. Only 251 of the 851 inventors have an NBC greater than or equal to 1. In the network diagram we have highlighted the 30 inventors with the greatest NBC in red, along with their first degree link. For the largest connected component comprised of 771 inventors, these 30 backbone inventors, roughly 4% of the population, are within one or two degrees of almost all other inventors in the largest connected component. They form the trust-backbone of the network.

IBP has seen the Innovation Backbone phenomenon in every government, university, and industry innovation network we have examined. In work sponsored by the Office of Naval Research we interviewed 71 backbone inventors from five different warfare center laboratories. We found that these inventors could be characterized as either: 1) the absolute subject matter expert in domain X, that everyone turned to for domain X problems, 2) the owner of a critical facility or capability, e.g. a nanoscience lab, or a modeling and simulation capability, or 3) they were the internal entrepreneurs who engaged with the customers to understand their needs, obtained resources from management, and then built networks of the first two types to deliver the required solution.

What are the implications for economic development? First, if a region is going to expend time and resources to attract a company it better make sure that company's innovation backbone is coming along. A company that loses a portion of its innovation backbone in the transition will be of lesser value to the region. Second, for companies in the region, the innovation backbone inventors understand how innovation works within their organization. They understand what fosters or impedes it. They are an invaluable source of insights on how to improve organizational and regional policies to increase innovation.

Multinational Enterprises, Bridges, and Weak Links

An interesting feature of many network concepts is that they scale. Concepts such as the Innovation Backbones and bridges linking multiple clusters can be applied at the regional level. For example, while individuals in an organizational innovation network can bridge two or more clusters, so too, large multinational enterprises can bridge multiple regional clusters across the nation, in fact, around the world.

In social networks there are strong and weak links. Strong links are between people or organizations that interact frequently, and tend to share common knowledge and views. Weak links reach out to other people or organizations who are not part of core group. The value of a weak link for innovation, in addition to being a bridge, is that it can provide access to knowledge and skills that are different from what is already present in the strongly linked core group.

Established regional innovation networks tend to be dominated by strong links within the cluster. Mudambi, et al, in their analysis of the evolution of industrial clusters[27] argues that large multinational enterprises (MNE), that have connections to multiple regional clusters, can perform the function of a weak link, connecting a cluster to knowledge and skills not resident in the cluster.

Innovation network mapping of large MNEs that have a presence in a region, can reveal potentially valuable extra-regional relationships that the MNE could facilitate for the region. What is required is policy to motivate the MNE to provide those weak links, and facilitate the access to additional knowledge and skills.

Group Innovation Networks

Group innovation networks are essentially problem solving teams. They can be short-lived or persistent. They can attack problems in a single technical domain or across multiple domains. The key to their productivity are policies and practices to encourage trust and the tacit-explicit dialogue.

Pentland[28] has shown that group productivity depends upon the topology of group dialogue. Groups that allow participation by all members are demonstrably more productive at solving problems. Groups dominated by an alpha-member are less productive. Again, allowing everyone to participate in the tacit-explicit dialogue increases the group's collective intelligence.

To "visualize" the dialogue Pentland's MIT team created devices that members wore to detect when they were in proximity of each other and participating in a dialogue. In this way they were able to map the topology of group dialogue. It is also possible to use

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[27] "Global connectivity and the evolution of industrial clusters: From tires to polymers in Northeast Ohio", by Mudambi, Ram, et al, Industrial Marketing Management, 2016.
[28] "Social Physics: How Social Networks Can Make Us Smarter", by Alex Pentland, Penguin Books, 2014.

email traffic, or meeting calendars to reveal a pattern of communications. For economic growth we believe the best policy is to provide training to group members and leaders on how to maximize dialogue and be open to a diverse spectrum of opinions. This has to become a cultural behavior pattern that is recognized and rewarded.

Finally, as in the inter-enterprise collaboration example, it is not uncommon to find an inventor X that has invented with N other inventors, where none of the other N inventors have invented with each other. In network terms this group would have a low clustering coefficient, and the number of potential additional conversations would obey Reed's Law. What is different here is that X has a personal trust relationship with inventors 1 thru N by the virtue of having co-invented with each of them. If X can be incentivized to introduce each co-inventor to the other N-1 co-inventors it would stimulate more tacit-explicit dialogues. Such a policy in networks terms is called triadic-closure, and works from the level of enterprises down to groups.

Individual Innovation Networks

Mapping neural activity in the human brain has seen significant advances in recent years, however, it is not at the point where we can map an individual's neural network at a level that reveals their ensemble of knowledge elements and skills. What we do know, is that education and training can increase a person's tacit knowledge and skills, and hence the ability to solve problems. Thus, policies that promote the development of relevant expertise[29] are essential. Particularly training and education that introduces alternative mental models that challenge the status quo.

The Innovation Genotype™

Innovation Network Mapping reveals the topology of the underlying social network, the network of trust relationships that fosters the collective intelligence, and social capital[30], responsible for the insights, inventions, and innovations of a group, organization, or region. What network mapping does not do, is reveal the domains in which that collective intelligence has the ability to acquire and apply knowledge and skills in the pursuit of economic growth. This is the role of the Innovation Genotype™.

The Innovation Genotype is based on a biological metaphor. As the genes of an animal's genotype express the proteins, that become the organs, that determine the animals ability to survive and thrive in its environment, so too, the creative people of an organization, or region, express the insights and inventions, that combine to form the innovations, that determine the organization's or region's ability to survive and thrive in the innovation economy.

We will use comparative analysis of the Innovation Genotypes of universities, government laboratories, and industry within a region, to identify, at a very detailed

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[29] "Peak: Secrets from the New Science of Expertise" by Anders Ericsson, Houghton Mifflin, 2016.
[30] "In Good Company – How Social Capital Makes Organizations Work" by Don Cohen and Laurence Prusak, Harvard Business School Press, 2001.

level, opportunities for research collaborations and knowledge transfer. Comparative genotype analysis will identify the technical domains for collaboration, enterprises with knowledge and skills in those domains, and even the specific individuals that should be convened to engage in the tacit-explicit dialogue.

Further, later in the paper we will discuss collaboration mechanisms and tools to take action on these detailed insights. Mechanisms to create a regional collective intelligence, and tools that both accelerate and reduce the cost of research and development.

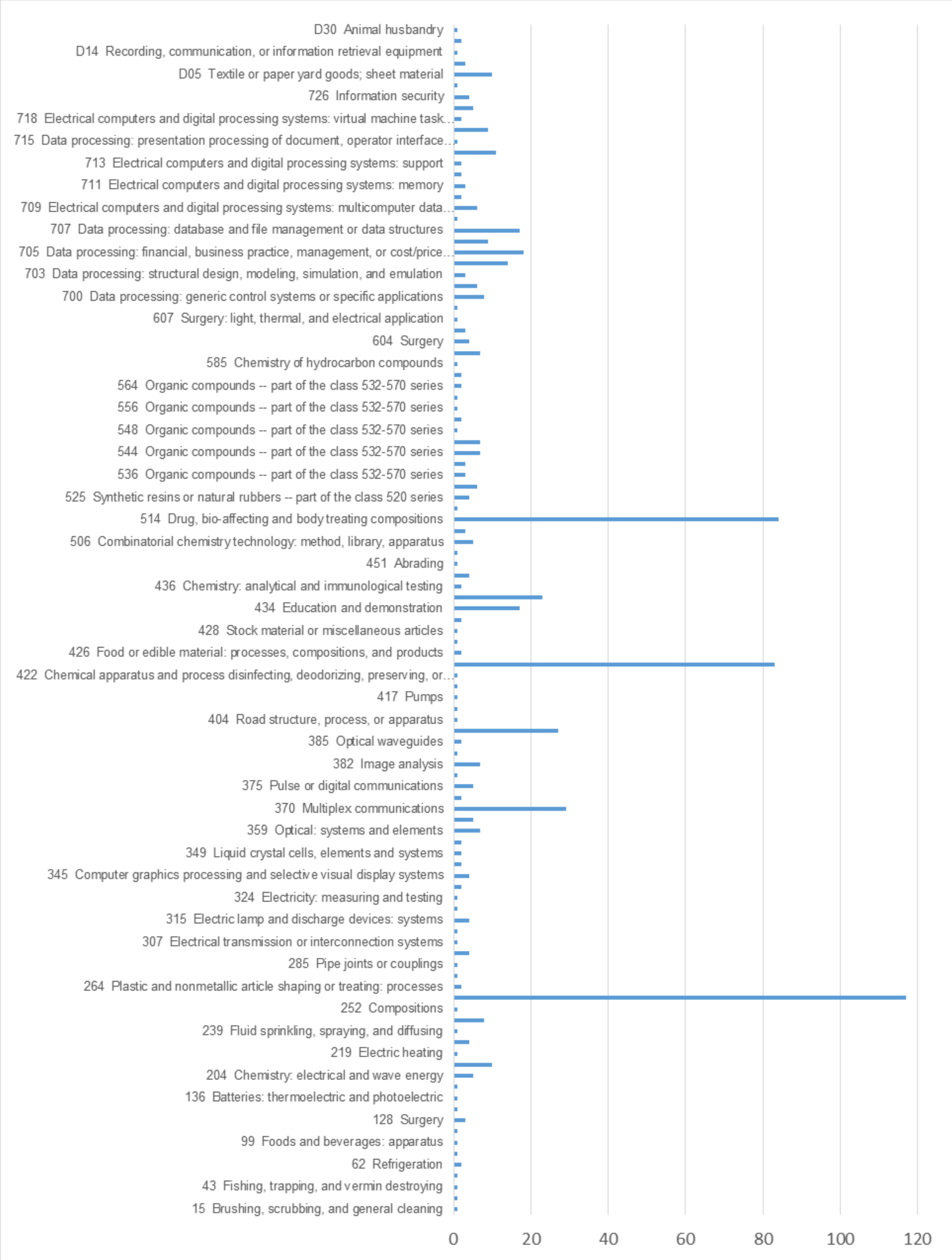
Regional Innovation Genotype

Genotypes can be calculated at all four levels, i.e. individual, group, organization, or region. Below is the genotype for the Greater Trenton Region (GTR)[31] of New Jersey. The left side of the genotype lists the U.S. Patent & Trademark Office primary classification codes[32] that one or more GTR commercial entities have invented in. The right side is a barchart indicating the number of inventions in that class generated by GTR companies. The data spanned January 2013 through October 2015. There were 1,060 inventions from 1,579 inventors that worked for 115 GTR based companies ranging in size from large multinational enterprises to startups.

An interesting observation is that these 115 companies have invented in 107 classes ranging from information and security, to fishing, trapping and vermin extermination. That is an impressive range of technical domains and suggests a large and diverse collective intelligence for GTR.

[31] The GTR was defined as a collection of cities provided by the Director of Economic & Industrial Development for the City of Trenton.
[32] Note, only every other code title is displayed due to resolution limits.

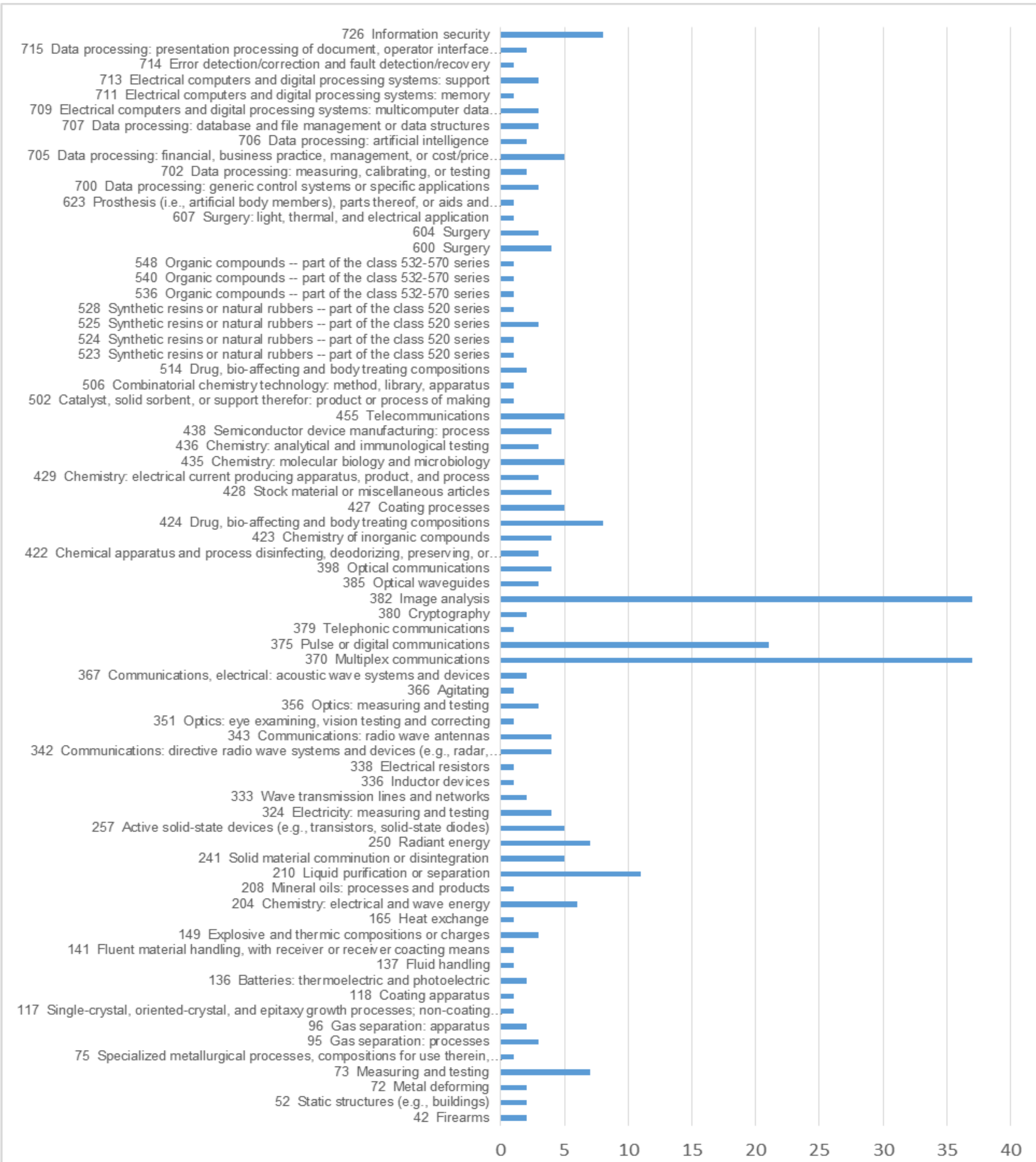
Figure 5: Greater Trenton Region Innovation Genotype™ - Class Code v. # Inventions



Enterprise Innovation Genotype

The next step was to calculate the genotype for the New Jersey Institute of Technology[33] (NJIT) which is shown in the figure below.

<u>Figure 6: New Jersey Institute of Technology Innovation Genotype™</u>



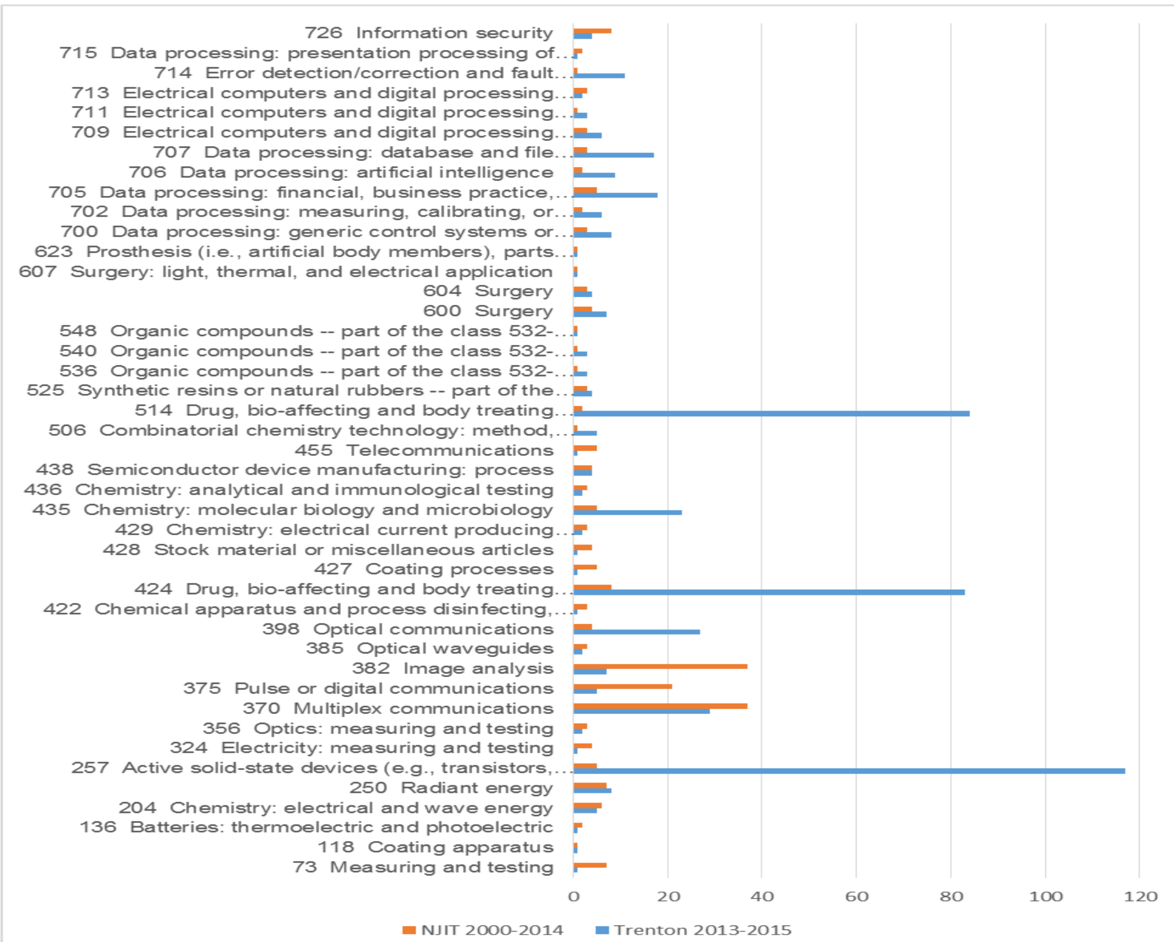
[33] This work was done in conjunction with [New Jersey Innovation Institute](#) a nonprofit owned by the New Jersey Institute of Technology.

The NJIT Innovation Genotype spanned the period from 2000 through 2014. NJIT's genotype for this period contains 299 inventions from 283 inventors spanning 72 classes.

Identifying Opportunities for Collaboration and Knowledge Transfer

To identify opportunities for collaboration and knowledge transfer between academia and industry we calculate the intersection of the regional commercial and university genotypes. Below is the graph for the intersection of the GTR and NJIT genotypes.

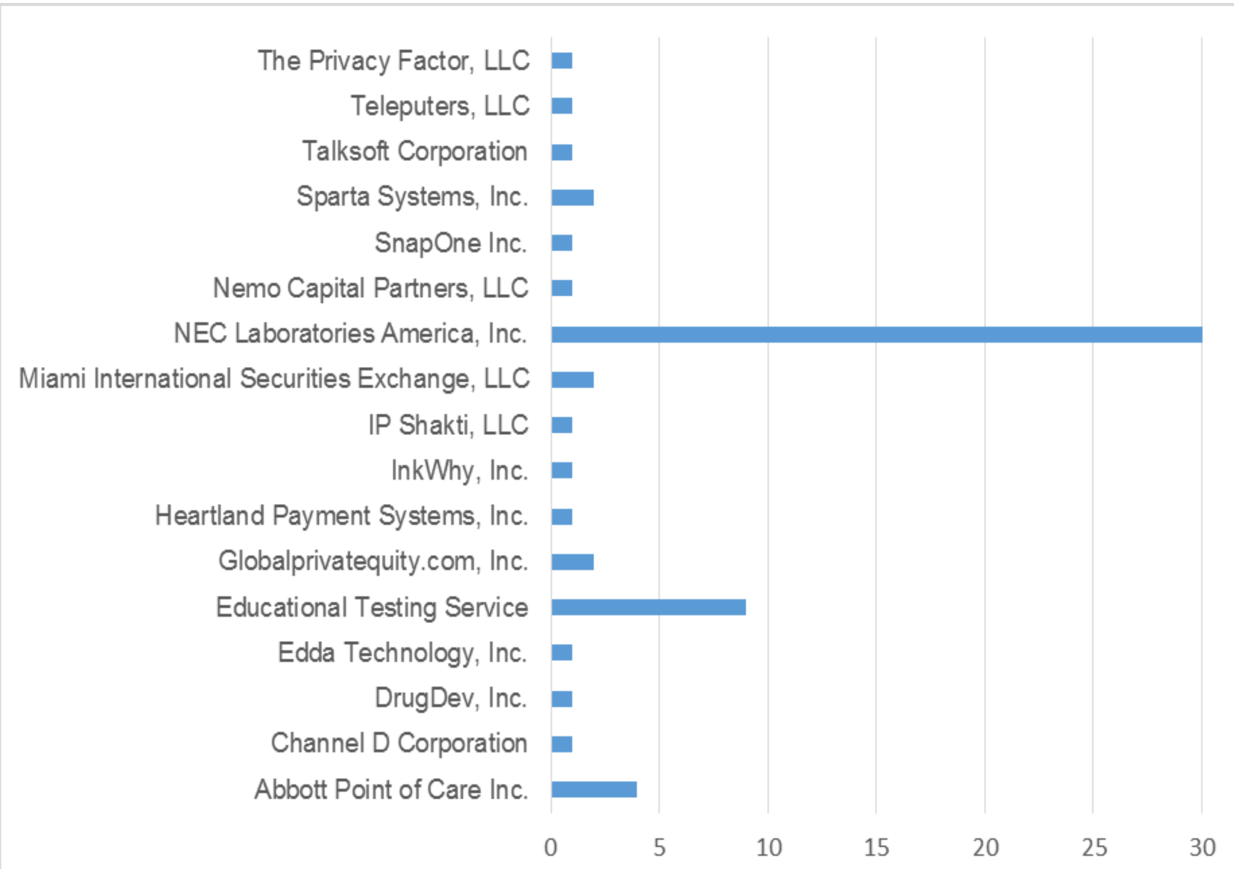
<u>Figure 7: Intersection of GTR and NJIT Innovation Genotypes™</u>



In the figure above the left side lists the US PTO classes in which both NJIT and one or more GTR private sector companies have separately invented in. On the right side the orange bars indicate the number of inventions from NJIT faculty, and blue bars indicate the number of inventions from the GTR private sector companies. There are 43 technical domains in which NJIT and one or more GTR private sector companies have both demonstrated knowledge and skills. Thus there are 43 domains that offer a potential for university-industry collaboration and knowledge transfer.

Genotype analysis can be further refined to focus on a specific industry. For example, US PTO classes 700, 702, 705, 706, 707, 715, and 726 are all related to the data industry. Given the emerging role of big data in the innovation economy, Trenton might want to focus on this industry with targeted economic development plans and policies. By identifying the GTR private sector companies that have invented in this industry we can identify specific collaborators NJIT should be focused on. This is shown in the figure below in the form of a modified genotype. This time the left column identifies GTR companies, and the right side the number of inventions they have in class codes related to the data industry.

Figure 8: Greater Trenton Region Data Sector Companies



These companies span a range of sizes, and as you can tell from their names, they span a range of markets from software, to finance, training, pharmaceuticals and healthcare. Every invention represented in this graph can be examined not only for the focus of the invention, but also for who the inventors are. This provides an opportunity for NJIT to convene a collection of inventors who all understand data industry innovations, but have different mental models on how data can be used in a range of markets. By analogy, all of these inventors speak the same technical language of data, but each comes with a slightly different dialect influenced by their market focus. This is, as Valdis Krebs claims, an opportunity for NJIT to create “serendipity as a service”[34]. The basic concept is to bring people together based on their similarities (they all speak “data”) and drive innovation based upon their differences (different market models for the role of data).

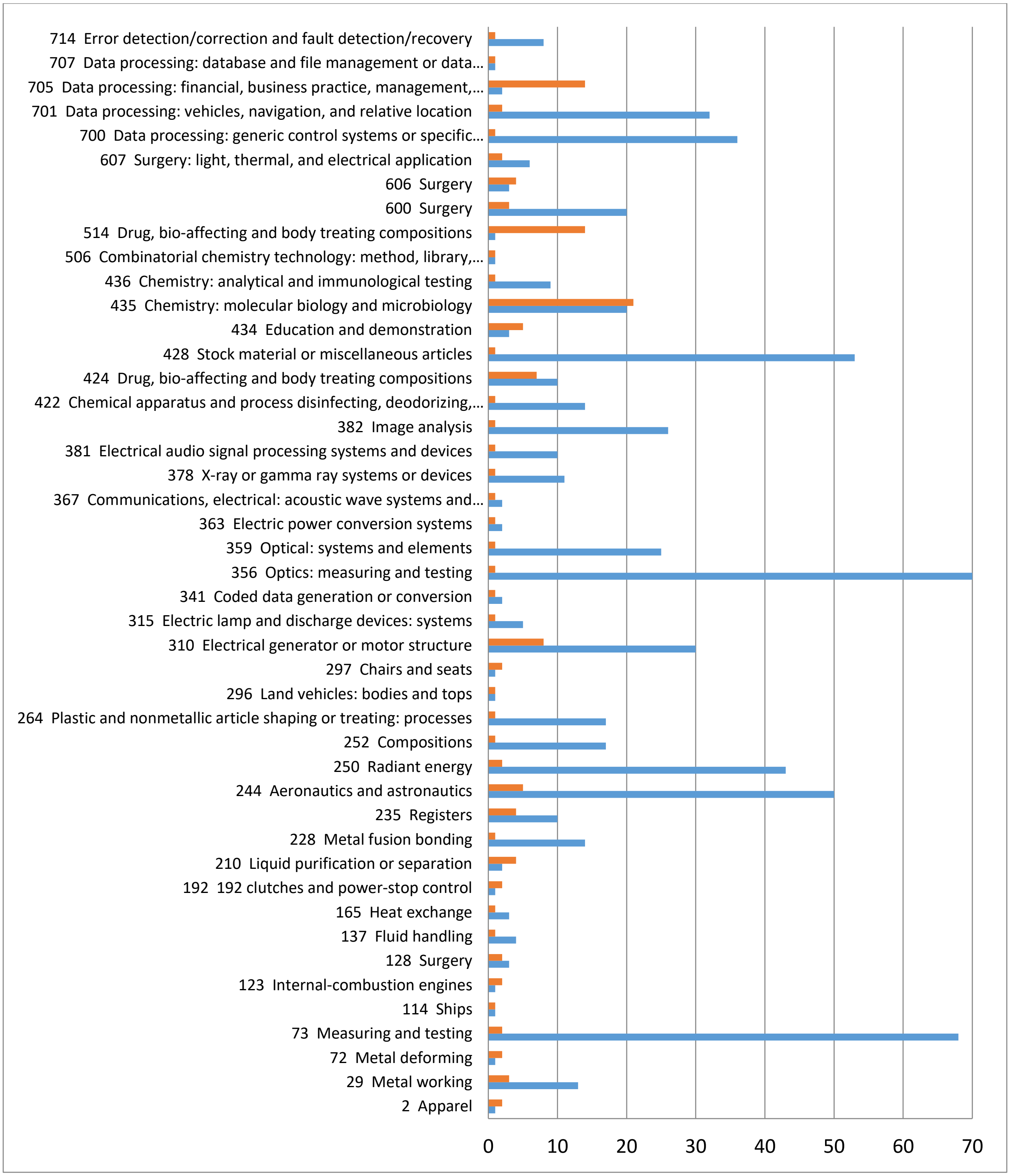
Collaborating with Federal Labs

The examples thus far have focused on academia and industry, but the same opportunity exists with the myriad of federal labs that have been the source of market creating technologies for decades[35]. These labs are particularly interesting because they often address leading edge technologies and can have generous licensing policies.

The figure below depicts the intersection of the genotypes of NASA and the Norfolk, Virginia region private sector for inventions from 2000 through 2014. Again, the left side of the chart lists the US PTO classes, the right side indicates the number of inventions in that class from NASA in blue and the Norfolk private sector in orange. There are 46 technical domains in which both NASA and one or more Norfolk private sector companies have invented in. That is 46 opportunities to explore collaboration, knowledge transfer, and licensing, that cover a very large spectrum of technologies.

[34] Krebs, Valdis, “BIF 8: Getting Technology and Sociology to Match”, the Business Innovation Factory.
[35] Mazzucato, Mariana, “The Entrepreneurial State: Debunking Public vs. Private Sector Myths”, published in the US by PublicAffairs™, a Member of the Perseus Books Group, 2014.

Figure 9: Intersection of NASA and Norfolk Private Sector Genotypes 2000-2014



Later in this paper we will discuss several vehicles for collaboration between government, universities, and industry that are fueled by the actionable data produced by innovation network mapping and genotype analysis.

Genetic Engineering, Attractions, Mergers, and Acquisitions

The enterprise or regional genotypes have many other uses. The first, genetic engineering, is to examine the current genotype and ask if it represents the genotype the organization or region needs to thrive in tomorrow's economy? What genes will be unnecessary in five or ten years? Which new genes, that represent emerging markets or disruptive technologies, does the organization or region need to acquire? Once the required genes are identified we can again use innovation network mapping and genotype analysis, but this time worldwide, to identify candidates to attract to the region, or candidates for acquisition or merger for an organization. This same analysis can be used by regional academic institutions to identify specific individuals to attract to the university, and develop the educational programs that will, in turn, attract and train the required human capital, or identify collaborators to build the storehouse of regional tacit knowledge in the desired domains.

Connecting the Centers of Insight to the Centers of Innovation

Having outlined the benefits of patents as an indicator of knowledge and skills with economic impact, it is important to acknowledge that some institutions, particularly some academic institutions, are more focused on scholarly publications than patents. In these institutions the ensemble of publications in peer reviewed journals is a better measure of the knowledge and skills of the institution.

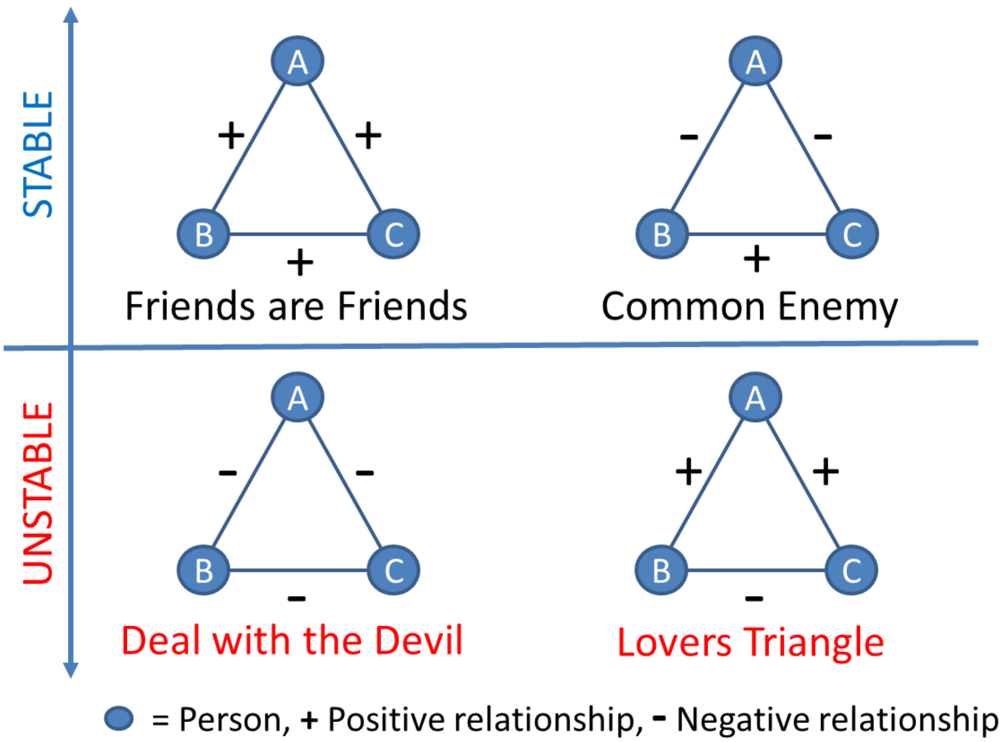
In such situations an analysis of scholarly publications can reveal the technical domains in which an institution has knowledge and skills. These domains can then be mapped into the relevant US PTO class codes to derive the institution's Innovation Genotype™. The "derived" genotype can then be used to find industry, government, and other academic institutions that are potential collaborators to create a higher order collective intelligence. Further, since the commercial candidates for collaboration have obtained patents in the given domain, they are more likely to have the capacity to move university knowledge in that domain from insights to innovations that create jobs and wealth.

Triadic Policy Analysis – Network Growth & Motivation

In social networks triads are the basic building blocks, and policy has a direct impact on a networks development at all levels. Some policies can grow a network and foster collaboration while others will destroy a network by pitting members against one another. The end result has a direct impact on the tacit-explicit dialog, the creative potential of an innovation network, and the value it can produce in the innovation economy.

Given any collection of three connected members of a network there are four possible triadic-relationships. Two of these configurations are stable and serve to grow or motivate the network. Two are unstable and tend to degrade the network over time. The figure below depicts these four triadic-relationship configurations.

Figure 10: The Four Triadic-Relationship Configurations



In the Friends-are-Friends triad, friends of A are friends of each other. This triadic-relationship tends to grow a network over time as friends of friends become friends themselves and develop trust. In the Common-Enemy triad B and C have a positive relationship with each other and a negative relationship with A. A is the common enemy of B and C. Politicians, Generals and CEOs have used a common enemy to motivate their networks since the beginning of time. In the Deal-with-the-Devil triad everyone has a negative relationship with everyone else. In this triad you sometimes find two members team up temporarily to defeat the third member, only to return to being enemies again. Finally, the second unstable triadic-relationship is the Lovers-Triangle. In this triadic relationship A has something that B and C both want, but A can only give it to one of them. B and C will work against each other till one wins the prize, and the other is defeated. The Lovers-Triangle is the foundation of many grant policies and much romantic literature.

The implication for economic policy is that we can use triadic-relationship analysis to design better policy, policy that is based on the two stable triadic-relationships and avoids the unstable forms.

As an example, consider financial policies that on the surface appear to be well intended, but ultimately can have unintended negative consequences on an organization's underlying social network. Prior to the early 90s Navy laboratories received "block funding". Each lab was given money to conduct research and development, which in the lab's opinion, would advance the frontiers of naval innovation. Congress, in an effort to make the labs more customer centric, stopped block funding and gave the money to the Fleet. Labs had to compete with each other for the funds from the Fleet. The result is a Lovers-Triangle relationship between labs and the Fleet. Each lab would make a proposal to the Fleet and only one would win.

Upon examining twenty years of patents, from five warfare centers, not a single invention with co-inventors from multiple labs was found. Interestingly there were many US PTO class codes in which two or more labs had invented in, i.e. there were many intersections between the Innovation Genotypes of the five labs indicating the potential for collaboration. So while this policy may be sound from a fiscal perspective, it has very negative unintended consequences on innovation.

As a positive example consider the Naval Research Laboratory (NRL). At the time of our study Dr. Snow was the director of the NRL Institute for Nanoscience. This is a state of the art facility that is critical for NRL researchers in this field. Dr. Snow had Naval Innovative Science and Engineering funds that he could allocate for use of his lab. His funding policy focused on growing NRL's internal network. Specifically, he would only consider proposals that involved two or more groups from NRL creating Friends-are-Friends triads. In our interview with Dr. Snow he felt that his policy was responsible for growing the nanoscience network within NRL. While we didn't have the data to separate the Institute for Nanoscience out from the rest of NRL, NRL was the most highly connected of the five Navy labs we examined.

It is hard, if not impossible, to anticipate all of the potential consequences of a policy. However, triadic-relationship analysis is a tool that can help economic development policy makers increase the number of positive outcomes of stable and motivating triads, and avoid the truly disastrous consequences of policies that create unstable triads.

Regional Mechanisms for Economic Growth

We have explored the use of network mapping and genotype analysis from the regional level down to the micro-foundation for economic growth. Next we will examine mechanisms for economic growth that are fueled by the data these analyses produce, the mechanisms that will help a region go from insight to innovation generating economic prosperity. All of these mechanisms are designed to facilitate and increase the quality and quantity of tacit-explicit dialogues, and introduce new planes of thought and mental models to fuel the most valuable bisociations.

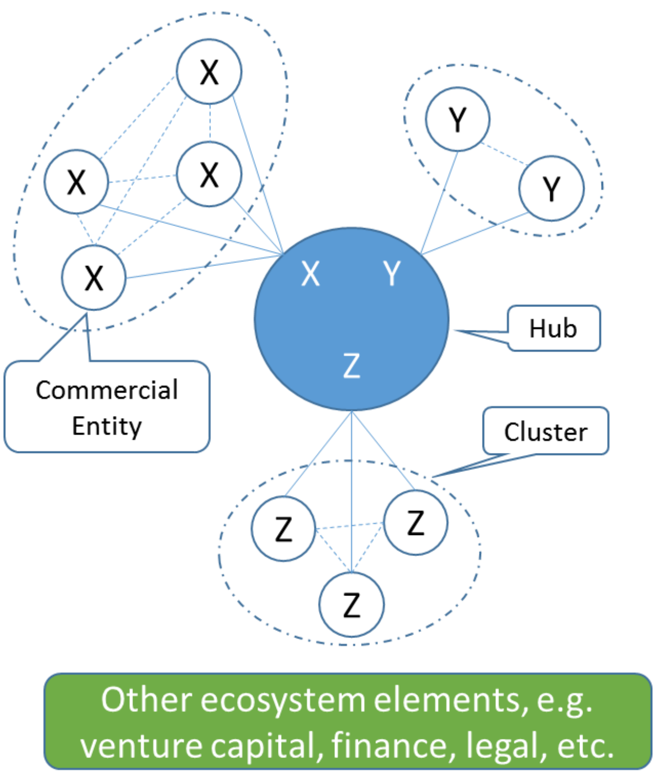
Collective Intelligence Clusters

Collective Intelligence Clusters (CIC) are all about connecting creative people based on similarities and generating new knowledge based upon differences. The structure of the CIC mechanism is shown in the figure below. The Hub, large blue circle, represents a "neutral" organization, for example a university, not-for-profit, or government organization that has expertise, and intellectual property in relevant technical domains X, Y, and Z. The smaller white circles represent commercial entities, large and small, who may, or may not be competitors, that also have expertise and intellectual property in one or more domains X, Y, and Z.

Hubs facilitate the dialogue between the inventors of a domain on the challenges, opportunities, and future direction in that domain. Connecting them on similarities creates a cluster (dotted lines/circles) generating a greater collective intelligence for the region and driving invention in that domain.

In some sense this is analogous to the structure of the semiconductor industry's SEMATECH[36], but with the university or government lab taking the action to convene the commercial entities. Like SEMATECH these clusters would create knowledge and intellectual property on the common platforms that all competitors in X, Y, or Z need to compete, but that no one entity can easily fund on their own. For example the SEMATECH consortium conducts research and development to advance chip manufacturing by jointly solving problems related to new materials, processes, and equipment for semiconductor manufacturing, which all members need to compete in the industry.

Figure 11: Collective Intelligence Clusters



The CIC structure might vary in terms of formality, ranging from something akin to a community of interest to a formal legal structure such as SEMATEC. A CIC might start out as a Hub facilitated community of interest, that as trust grows, and competition demands, morphs into a more formal legal entity focused on increasing the region's competitiveness in a given domain. The green box at the bottom represents the other ecosystem elements required for success, e.g. a link to the financial and venture capital communities, legal support, incubator space, accelerators, licensing of university or other intellectual property, etc.

The CIC may even decide to create a common pool of intellectual property to which all members have some rights, or to jointly fund basic research that has potential benefit to all members. The idea is to

[36] Gary Markovits was one of IBM's representatives to SEMATECH in its early stages.

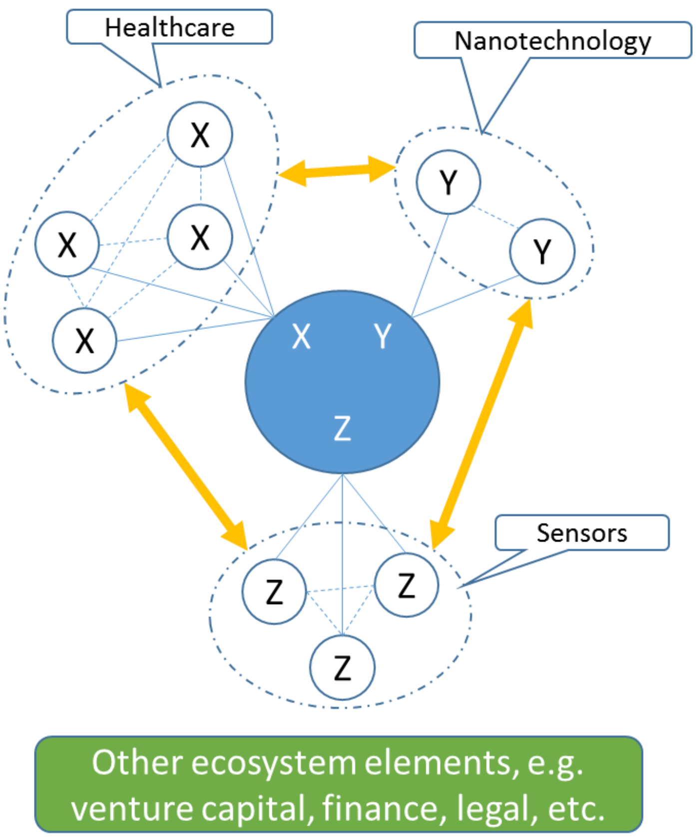
create the collective intelligence that will benefit the region, and result in higher competitiveness, job growth, and prosperity. A 2013 MIT study[37] emphasizes the importance of a convening function, coordination and collaboration mechanisms, and risk-reduction and risk-pooling, all of which are accomplished by the CIC.

Innovation at the Intersections

The CIC structure also enables the Hub to facilitate finding the often breakthrough, or even disruptive innovations at the intersections[38]. In the figure below the yellow arrows between clusters represent the opportunities for innovation at the intersections.

In this example the clusters are "Healthcare", "Nanotechnology" and "Sensors", three domains that are ripe for innovation at the intersections, however, it could be any collection of domains. The role of the Hub is to search for, identify, and then convene members of multiple clusters to engage in interdisciplinary innovation.

Figure 12: Innovation at the Intersections



Another role of the Hub is to introduce, train, and guide members in the use of tools to manage the interdisciplinary collaborations.

In either the CIC or innovation at the intersection structures a key role of the Hub is to establish a neutral ground and practice the behaviors that will generate trust between all members. This will include establishing the policies, practices, legal and contractual formalisms, and acceptable behavior patterns that everyone can agree to. It also means that the Hub has to provide leadership by walking the walk.

Another role of the Hub is to help its members leverage knowledge from outside of the region. This might be accomplished via the Hub's long-links to other clusters or institutions outside of the region, or by employing a meta-idea such as Insight Driven Innovation,

[37] "A Preview of the MIT Production in the Innovation Economy Report", Massachusetts Institute of Technology, February 22, 2013.
[38] "Medici Effect: What You Can Learn from Elephants and Epidemics", by Frans Johansson

described below, which uses intellectual property to leverage the world's investment in research and development.

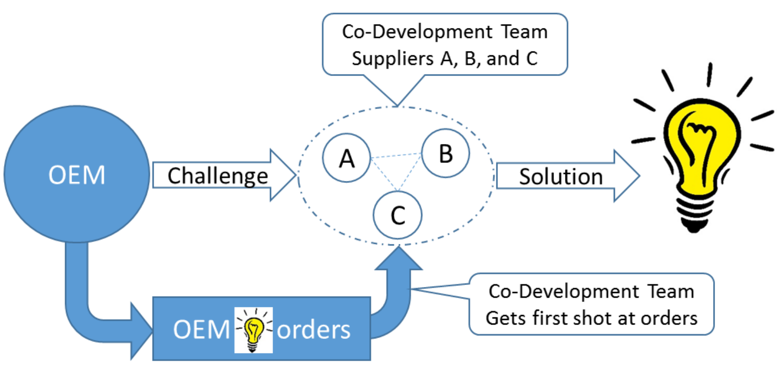
Meta-Ideas

Paul Romer distinguishes between an "idea" and a "meta-idea"[39]. The former is the recipe for a novel combination of elements that creates new value, the latter is an idea that facilitates the generation and propagation of new ideas. In our work with the Navy and commercial clients we have found that it is possible to use patents from a wide spectrum of domains to systematically stimulate the tacit-explicit dialogue and create those "weak links" to outside knowledge that increase the group's collective intelligence. This process is a meta-idea. The process, called Insight Driven Innovation™ (IDI), starts by building a model of the problem space and identifying the "must solve needs", past solution approaches and their shortcomings, technology independent attributes of an ideal solution, and analogous challenges in other domains. This information is used to create search strategies to find a set of relevant inventions from as many different domains as possible. Every week the CIC participants are fed one or two new inventions which they decompose into their elements and relationships, and brainstorm new combinations of elements and relationships that might solve the problem. In a successful ten week pilot that involved four five-member teams, each focused on a different problem, the Navy documented a savings of 2 years and $10 million dollars of R&D[40].

Co-Development Teams

The third mechanism is essentially Nike's successful Co-Development Team (CDT) model. This mechanism is aimed squarely at commercial innovation and the rapid collaborative creation of jobs and wealth.

Figure 13: Co-Development Teams



In this adaptation of the Nike co-development model[41] Nike is replaced by any large regional original equipment manufacturer (OEM large blue circle). With the help of the Hub, or from the OEM having participated in the CIC mechanisms, a team of suppliers, A, B, and C is formed, this is the Co-

[39] "Economic Growth" by Paul Romer, Liberty Fund, Inc., 2008.
[40] "Bridging Small Worlds to Accelerate Innovation", by Markovits, et al, Defense AT&L: September-October 2005.
[41] "Nike's Extended Co-Development Network", Featured Practice of the Corporate Executive Board, 2003.

Development Team (CDT). The OEM communicates the challenge, which is likely to be proprietary, to the CDT. The CDT agrees to confidentiality with the OEM and further agrees to collaborate to find a solution acceptable to the OEM. In exchange for A, B, and C, who could be competitors, sharing their knowledge and creating a solution, the OEM offers them the first right of refusal for the OEM's orders for the solution. The CDT also agrees that if they cannot fulfill all of the OEM orders, the OEM can then reach out to other suppliers to have them fulfill the excess orders.

The co-development model is subject to "free-riding", the state in which one member of the CDT does not contribute equally. The co-development model allows the other CDT members to turn the free-rider into the OEM who then acts as the judge and jury. If the OEM determines that one member of the team is a free-rider, then the free-rider becomes the last supplier to get orders from the OEM, and in fact, risks getting no orders at all.

The Hub has many important roles. First, assuming the co-development model will be exercised across the region with many different OEMs and many "suppliers" there is a need for a standard set of policies, practices, contracts, etc. like those Nike has developed, but that the OEMs may not have. To facilitate formation of multiple co-development networks the Hub would create a standard package, and the training for members of the co-development network to understand their obligations under this mechanism.

Another role of the Hub could be to provide the neutral facilities for the CDT members to collaborate in. If subject matter experts from the hub participated in the collaboration they would be in a position to act as "expert witnesses" should a free-rider challenge arise. They would also be in a position to act as a mediator and prevent the free-rider situation. This could be a valuable service offering of the Hub.

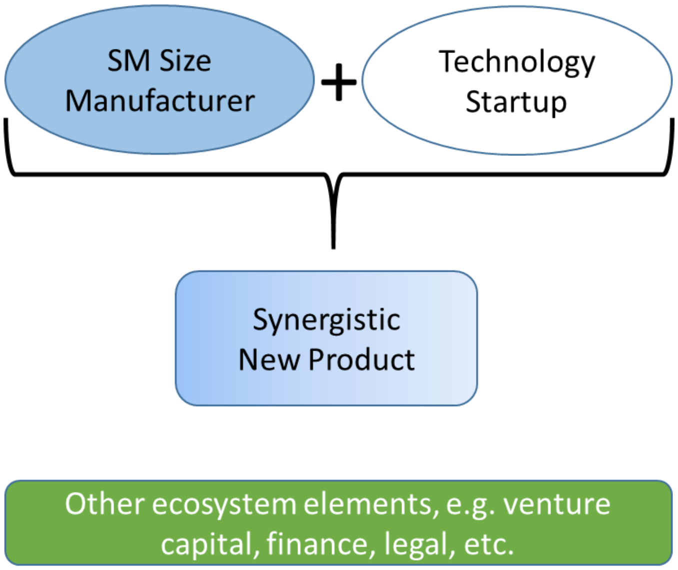
Finally, the Hub could provide links to the other ecosystem elements like venture capital, and provide the tools and training to successfully run a co-development collaboration.

Technology Enhanced Manufacturing

The fourth mechanism seeks to create jobs and wealth by synergistic collaborations between startups and mature small to medium size manufacturers.

Many small to medium size manufacturers lack R&D and new product development capabilities. Conversely, many startups have creative technologies but lack the ability to manufacture, market, distribute, and service the potential products based on their creative technologies. The objective is to connect a small to medium size manufacturer with a technology startup to create a synergistic new product or service that takes advantages of each member's strengths.

Figure 14: Technology Enhanced Manufacturing



This "connection" might be as simple as an agreement to collaborate in creation of the product or service and an agreement to share in the costs, revenues and profit. Conversely it could be a merger that creates a whole new entity. In this latter case it might involve a venture capitalist with a controlling investment in the startup that uses a leveraged buyout of the manufacturer to create the new entity. The point is, there is a large range of potential relationships that might allow the parties to "walk together" before they "run together" thus increasing the probability of success.

Technology Enhanced Manufacturing could increase the probability of startups making it across the "valley of death" thus reducing the risk of investments in them. It would also help to revitalize small to medium size manufacturers who tend to get locked into a single product model and end up being disrupted by changes in the industry.

The TEM model can be generalized to link any "innovator" with any "producer". An example of this is Apple's App Store where the innovator could be a lone programmer in the garage and the producer is the App Store. In short, it is linking those with ideas to those that can create value from them.

Again there are many possible roles for the Hub to play. The Hub could actively identify the potential manufacturer + startup combinations, and convene them to explore the opportunities. The Hub could again create a standard package of policies, practices, legal agreements and contract forms to facilitate the union. The hub could contribute facilities, researchers and intellectual property in exchange for a piece of the pie.

Measuring Our Capacity for Innovation

The objective of economic development policy in the innovation economy is to increase the capacity for innovation of the region, and the organizations, groups, and individuals that comprise the regional innovation networks. To assess the efficacy of any ensemble of policies we need a set of metrics. Fortunately, the National Innovation Initiative 21st Century Innovation Working Group defined four generations of innovation metrics[42] which are presented in the table below.

[42] "Innovation Metrics: Measurement to Insight" by Nicholas Vonortas, George Washington University, and Egils Milbergs, President, Center for Accelerating Innovation.

Table 1: The Four Generations of Innovation Metrics (NII)

Gen 1: 1950s-60s	Gen 2: 1970s-80s	Gen 3: 1990s	Gen 4: 2000+
R&D Expenditure	Patents	Surveys	Intangibles
S&T Personnel	Publications	Indexing	Networks
Capital	Products	Benchmarks	System Dynamics
Tech Intensity	Quality Change		Knowledge
			Demand
			Clusters
			Mgmt Techniques
			Risk/Return

Generation one and two took a "black box" approach to innovation and measured the inputs and outputs without considering the internal processes. Generation three compared multiple black boxes and began to identify best practices. Generation four goes even further and attempts to understand innovation in the larger context of the economic ecosystem.

The authors emphasize that the generations are additive. Most organizations are currently using the first three generations, and should continue to do so. The innovation network and genotype models allow organizations to apply network science and add more of the fourth generation to better measure results and guide their policy interventions.

Creating a Culture of Innovation

ITIF notes that innovation is the product of ecosystems rather than individual companies[43]. We agree, and suggest that the ultimate goal of economic development should be to create a regional culture of innovation. A coherent system of visions, strategies, policies, practices, and facilities that enable the behaviors that will create a sustainable collective intelligence to ensure the region's ongoing success in the innovation economy.

Work sponsored by the Naval Surface Warfare Center Carderock Division has enabled IBP to develop a model of culture as a form of collective intelligence. Where individual intelligence is the ability of a person to acquire and apply knowledge and skills, collective intelligence is the ability of a network of people to acquire and apply knowledge and skills at a rate that far exceeds that of any individual. This model explains the relationships between vision and strategy, policies and practices, the

[43] "Innovation Economics – The Race for Global Advantage", by Atkinson and Ezell.

desired behavior patterns, and the resulting network that creates the organization's or region's social capital -- the stock of active connections among people. This social trust, mutual understanding, and shared values and behaviors is what binds the members of human networks and communities, and makes cooperative action possible[44].

This creates a higher economic development opportunity. The techniques described above inform the creation of the networks and micro-foundational process that will increase our capacity for innovation. The model of culture as collective intelligence will guide leadership in working with both the organizations and the region in creating the policies and practices that will maximize innovation and economic development.

Conclusion

The pace of Schumpeterian change is faster than ever before. In the innovation economy, technology enabled startups are toppling long standing incumbents and exceeding their market cap in record times. These changes are fueled by insights, inventions, and innovations generated by human collective intelligence. This collective intelligence arises from networks of creative people acquiring and applying knowledge and skills to create new combinations that change behaviors and create value for society. And we identified the micro-foundation of collective intelligence as the tacit-explicit dialogues between connected and motivated people.

We argued that the ecosystem supporting the innovation economy can be thought of as a collection of innovation networks spanning the individual, group, organization and region, each level comprised of networks of lower level networks. This bisociation of economic thought and network science enables the visualization, characterization, and quantification of these innovation networks – and thus the economic ecosystem.

We presented examples of innovation network maps at regional and organizational levels that exhibited unique topologies and characteristics that influenced the region's or organization's capacity for innovation. These properties highlighted organizations and individuals that exhibited best-of-breed characteristics from which economic developers could glean insights to create better policies and programs.

Further, the paper defined a new concept called the Innovation Genotype™, and showed how analysis of the intersections between industry genotypes, and those of university or government labs, could identify opportunities for collaboration and knowledge transfer to create a robust regional collective intelligence. We also suggested several mechanisms to facilitate collaborations between government, universities and industry, and a meta-idea to catalyze collaboration.

[44] "In Good Company: How Social Capital Makes Organizations Work", by Cohen, Don and Prusak, Laurence, Harvard Business School Press, 2001.

Finally, we suggested that the ultimate goal of economic development should be to create a regional culture of innovation. A coherent system of visions, strategies, policies, practices, and facilities which enable the behaviors that will create the greatest collective intelligence.

Just as geologists use technologies to map the earth's substructure to identify likely deposits of gemstones, we hope we have provided the economic development community with the technologies to find the innovation gemstones that will be the basis of a sustainable competitive advantage in the innovation economy.

Government-University-Industry Research Roundtable Opportunity

In the terminology of this paper the Government-University-Industry Research Roundtable (GUIRR) is the Hub of a national Collective Intelligence Cluster. As the organization itself notes, "GUIRR provides a forum like no other, where a unique mix of sectors comes together to understand how the other side thinks. The participants are senior-most leaders within their organizations, a tribute to the "convening power" of the Academies. GUIRR offers "neutral turf" and closed doors for very frank discussions that builds bridges and spurs accelerated activities."[45]

The membership of GUIRR represents a collection of some of the most powerful innovation networks in the nation that span an extremely diverse genotype. As such, the GUIRR membership has a unique opportunity to develop and recommend policy and programs that will increase our national collective intelligence, and ensure our nation thrives in the world's innovation economy.

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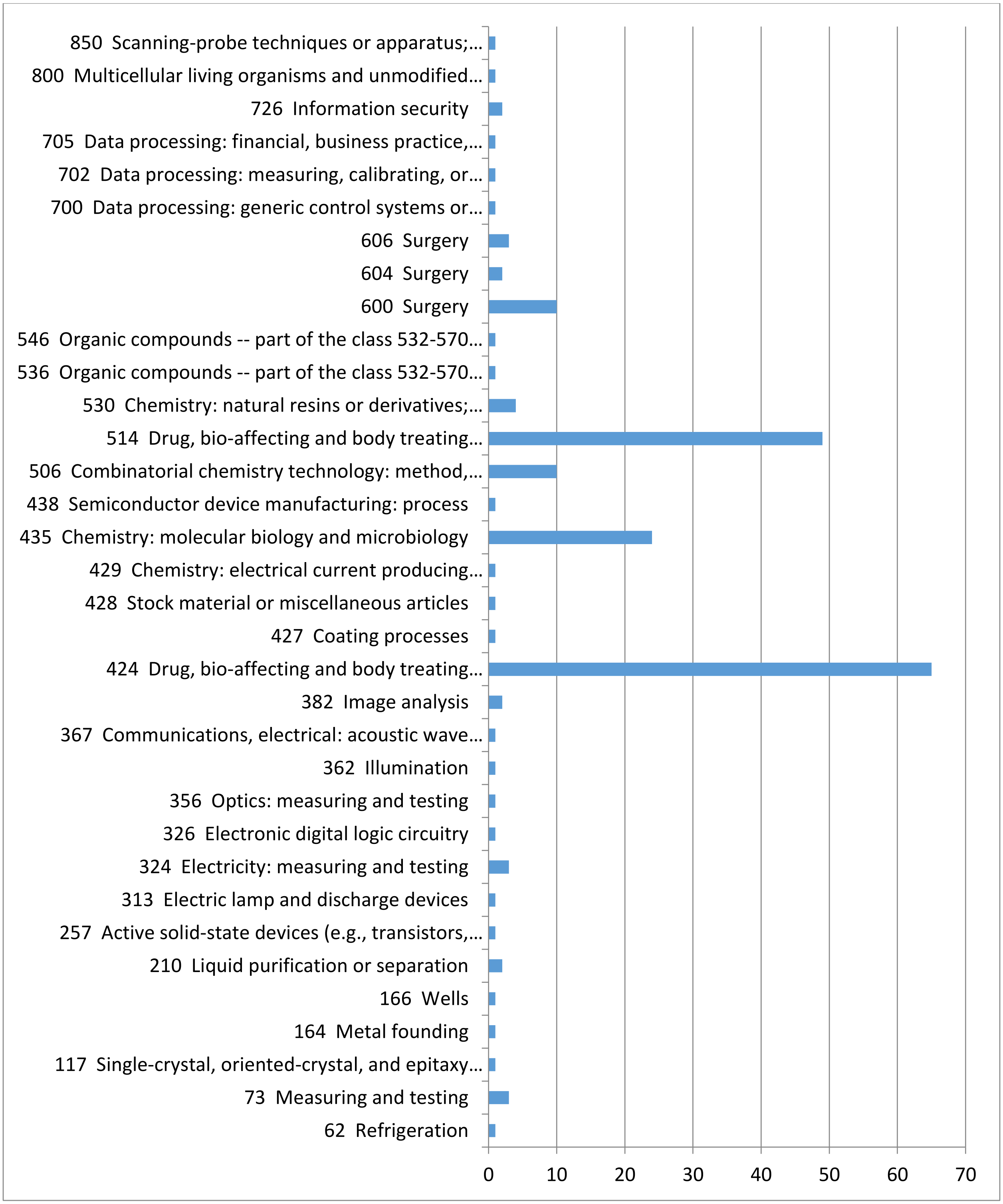
[45] GUIRR website, "What Makes Us Different", viewed 15 February 2017.

Appendix: Maryland Inter-Enterprise Collaboration Innovation Genotype™

Figure 15: Maryland Inter-Enterprise Collaboration Innovation Genotype™



While there are many inventions related to medical or biological innovations there are a sufficient number of inventions in other classes to suggest that the collaboration was related to the practices of the enterprises and not their technical domains. Further analysis will be required to confirm this.

