

Complexity and Innovation Dynamics

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1. Artifacts and organizations

Human life is impossible to conceive without two fundamental ingredients: *artifacts* and *organizations*. Just about everything we do involves interactions with artifacts, from the clothes we wear and the buildings we inhabit, to the devices through which we communicate with one another and the tools and technologies we use to make ever more artifacts. And almost all of our interactions depend for their setting, purpose and rules on organizations, whether they be churches, businesses, government agencies, political parties, law courts, police forces, armies, social clubs – or even friendship networks on internet.

We human beings didn't invent either artifacts or organizations: biological evolution did. Both *fashioning artifacts* and *deploying collective action* are evolutionary strategies that have been around a long time. Artifacts allow the biological individuals and species that make and use them to wrest more usable matter and energy from their environments, allow more of them to live in a given environment, and sometimes allow them to live longer and dedicate more of their time and energy to reproduction. Some biological engineers construct exquisite and complex artifacts, from the fungal agriculture of leaf-cutter ants, through the durable nests of weaverbirds and the beaver's temperature-controlled aquatic dwellings. In addition, many of these artifacts transform the environments of other biological entities as well as those that construct them, in ways that may be positive or negative for these entities' biological functionality of *survival* and *reproduction*.

Examples of collective activity among biological conspecifics range from the production of stalks and fruiting bodies by aggregations of single-celled slime molds, through ant and termite colonies, to prairie dog communities, wolf packs and primate bands. These societies, like human organizations, are characterized by differentiation of function among component individuals, not all of which necessarily benefit (or benefit equally) from the collective activity, and by control mechanisms that ensure some level of coordination among component individuals and processes.

But even if we didn't invent them, nothing in biology remotely compares with the use that we human beings have made of these two strategies. The number and complexity of the artifacts we have developed over the millennia, and in particular over the past few centuries, and the variety of activities we have organized around these artifacts, has no counterpart in the pre-human world. If three million years ago, our ancestors had

essentially one kind of artifact, and fifty thousand years ago, maybe several hundred, today's inhabitant of New York City can choose among 10^{10} different bar-coded items (Beinhocker, 2006, p. 9), not to mention a host of other material, informational or performative artifacts currently produced by human beings for the use of human beings! Even more unprecedented are the diversity of forms and the scale of the organizations we have created, through which we collectively carry out political, economic, social and cultural functions that seem far removed from the overriding biological functional imperatives of survival and reproduction.

Over the past decade, my colleagues and I have been working out a complexity-based theory of innovation that is intended to explain how human beings have managed to generate this explosion of artifacts and organizations – and the new functionalities they make possible. The theory starts from the premise that all artifacts have a history, as do the organization of the interaction modalities among people in which these artifacts figure. The aim of the theory is to describe and analyze the processes through which artifact and organizational histories are realized and interconnected. In particular, the theory addresses the following questions:

- How do new artifact types come into being?
- How do their tokens proliferate and become incorporated into patterns of human interaction?
- How so these interaction patterns give rise to new forms of organization, and how do the resulting organizations support and structure interactions among humans, artifacts and organizations?
- And how are new patterns of interaction generated?

In this chapter, I will sketch some of our answers to these questions, emphasizing two key theoretical concepts: *exaptive bootstrapping*, a positive feedback innovation dynamic (section 4), and *generative relationships*, the locus at which new attributions of functionalities arise (section 5). First, though, I explain what we mean by “a complexity-based theory of innovation”: what we mean by *complexity* (section 2) and what this implies for what we mean by a *theory* – and in particular, a theory of innovation (section 3).

2. Complexity

The term “complexity” is entering more and more frequently into scientific discourse, both academic and popular. Not surprisingly, in this swirl of activity, the meaning of complexity has not yet settled down, and different authors use the term in very different ways:

- For some, it refers primarily to a developing toolkit of inferential and modeling techniques, most of which depend on substantial computation.
- To others, complexity is an intrinsic and (at least in principle) measurable attribute of certain classes of mathematical or computational systems.
- Still others use the term more loosely to apply to broad classes of physical, biological or social phenomena, which are described by means of such concepts as *emergence*, *self-organization*, *robustness* and, more recently, *networks*.

In this chapter, I rely upon a particular variant of the third of these interpretations of complexity. When I say that the theory of innovation explored in this chapter is

“complexity-based”, I mean that it builds upon a perspective characterized by *dynamic interactionism* and *organization thinking*. Let me now explain what I mean by these two terms.

A *world* is a set of phenomena that a scientist seeks to study. Worlds are unlabeled places, a flux of matter, energy and information. Scientists try to make sense out of the worlds they study by attending to certain kinds of *patterns* in this flux. When the scientist decides *which* kinds of patterns he will attend to, for the world he seeks to understand, he is making an ontological commitment: *this* world is made up of *these* kinds of things, and not others.¹ His ontological commitments determine what the scientist can talk about, and they have very important implications for what count for him as problems – and what count as solutions.

Dynamic interactionism describes a class of ontological commitments. Let’s refer to a generic member of this class as DIOC. For DIOC, the world is composed of *entities*, which have certain *properties*. Entities *interact* with other entities, and as a result of these interactions entity properties can change. A particular kind of entity property is its *interaction modalities*, which specify with which other entities the entity in question can interact, and which properties of which entities change, and how, as a result of such an interaction. The patterns that matter for DIOC are functions of *histories* of entity interactions. In particular, DIOC is *constructive*: new kinds of entities, entity properties and interaction modalities can emerge in the course of interaction histories.

Virtually all scientists who identify with the streams of research that constitute complexity theory base their work on ontological commitments consistent with dynamic interactionism. This is not true, however, of the styles of theorizing that characterize many disciplines. Take economics as an example, and consider these leading styles of economic theorizing, on which various attempts to develop theories of innovation have relied:

- The ground floor of the ontology of standard *econometric modeling* is occupied by *variables*, not *interacting entities*.
- *General equilibrium theory* does commit to entities (or *agents* – firms and households – and *markets*), but does not provide an explicit representation of entity interaction, nor does it describe patterns in terms of histories of entity interactions or allow for the emergence of new kinds of entities.
- *Game theory* represents interactions explicitly and can describe patterns of interaction histories, but it too fails to provide an ontology that can serve as the basis for an endogenous account of the emergence of new entities, properties or interaction modalities.²

¹ The fact that most scientists inherit their ontological commitments from the disciplines in which they work, and as a result don’t think they are actually making ontological commitments but rather studying the world as it is – is completely irrelevant to the point I am making here. Nor am I saying that quarks and spin, genes and heritability, or markets and democracy are mere inventions of the scientists who first used these terms to describe patterns they were interested in understanding. Some ontological commitments give a lot more purchase on the flux of matter, energy and information that underlie the phenomena we observe and try to study than others!

² The theory of repeated games does allow for the emergence of strategies but not new rules for the game.

Thus, a commitment to dynamic interactionism requires a different approach to the problems and solutions of innovation theory than these standard styles of economic theorizing can offer.

Many of the key concepts of current complexity research gravitate around the idea of *organization*: emergence, self-organization, hierarchy, networks, modularity, robustness, scaling. One of the great unfinished projects of complexity research, first enunciated by Herbert Simon a half-century ago in his seminal papers entitled “The organization of complex systems” and “The architecture of complexity,” is to construct a theory of organization for complex systems, which can provide a unified context for thinking about the concepts mentioned in the previous sentence.³

- What do we mean by organization? *Organizations* are particular kinds of interacting entities, which can be characterized by three fundamental aspects: *structure*, *function*, and *process*.
- *Structure* is recursive: it has parts, which are themselves organizations. To describe an organization’s structure, one must identify its parts, the interaction modalities among its parts, and the modalities through which the organization interacts with other organizations. *Hierarchy* and *networks* are key concepts in describing organizational structure: the former, because of recursivity; the latter, because organizations engage in recurring patterns of interaction, which constitute networks – with organizations as nodes and recurring interactions as links.
- The *processes* associated with an organization describe the transformations (in the organization of its world) in which the organization may participate. Processes are supported by structure. To enact any of its processes, some of an organization’s parts must engage in interaction events, each of which requires some particular interaction modality. Instantiating the structural support for a given process may require the activation of other processes, which we can refer to as *management processes*. There are three principal kinds of management processes:
 - *recruitment*, which induces (even constructs) parts to participate in the process;
 - *differentiation* or *specialization*, which provides these parts with the requisite interaction modalities; and
 - *coordination*, through which the requisite interactions are arranged and enacted in a spatiotemporal order that achieves the appropriate transformation.
- The *functions* of an organization provide *directedness* to its actions, through their role in determining *which* processes the organization enacts, when the organization is in a context in which more than one process could be enacted.⁴

³ Simon’s theory, based on the idea of nearly decomposable hierarchies, is full of suggestive ideas, but it does not do the job. In particular, of the three aspects of organization discussed below, it is long on structure, weak on function, and almost totally ignores process. See Lane (2006) for an extended critique, along with a discussion of some other important contributions to a complexity theory of organization by Phil Anderson and John Holland.

⁴ Obviously, the concept of function is irrelevant for organizations that are never in such contexts – or if, when they are, chance rather than the organization determines which process is enacted. This is the case for physical systems. Function begins with biology.

An organization's structure, its processes and even its functions can change over time. Indeed, many human organizations can enact processes through which they themselves transform some or all of these.

For a scientist who commits to *organization thinking*, the important entities in the world under study (generally including the world itself) are organizations. The scientist's job is to investigate *all the relationships* among structure, function and process in the organizations that comprise this world: in particular, how structure supports processes, how processes build and maintain structure, how structure is shaped by function and function is enabled by structure, and how function triggers the enactment of processes and the enactment of processes effectuates function. Of particular interest are those relationships implicated in the constructive processes through which new organization *emerges*, and existing organizations are *transformed*, over time.⁵

3. What is a “theory of innovation”?

From one point of view, a “theory of innovation” is an oxymoron. If, as many scientists believe, a theory is supposed to lead to verifiable predictions of the phenomenon under study, then a theory of innovation should predict innovations – which would mean the process leading to innovations the theory was meant to explicate is just an historical dead-end that could be replaced as innovation-generator by the theory itself! Of course, this is silly: the theory could illuminate aspects of the process without “predicting” the new artifacts that were the process outcomes of primary economic and social interest.

But which aspects? This issue is anything but trivial: one of the first concepts my collaborators and I had to come to grips with in our theorizing was the nature of the uncertainty that surrounds innovation, and what limitations on predictability this uncertainty implies. Thinking about this problem led to the formulation of the concept of *ontological uncertainty*, which is explored in Lane and Maxfield (2005). Unlike truth uncertainty, in the face of which agents can formulate a logically complete set of consequences of the effects of the action possibilities they are deciding among, even if they do not know with certainty which of these consequences will actually occur, agents facing ontological uncertainty do not even know the identity of the other agents that will mediate the effects of their actions, nor do they know with which criteria they will evaluate these effects: these agents and criteria are under construction, in the course of the very processes in which our agent must act. Thus, agents facing ontological uncertainty cannot even formulate propositions that describe the possible consequences of their action, much less predict which consequences will actually occur. The more we thought about ontological uncertainty and its implications, the less attractive we found the very idea of prediction – predicting *any* quantitative variable – as the goal of a theory of innovation.

We ended up by adopting the following idea about what a theory of innovation ought to be – and what it ought to do. The theory itself should provide a minimal ontology for

⁵ See Lane et al. (2009), Read et al. (2009), and van der Leeuw et al. (2009) for a detailed discussion of organization thinking and its implications for understanding innovation and social change.

recounting historical episodes of innovation in a causally convincing way. By *ontology*, we mean

- kinds of *entities* and their *properties*;
- *interaction modalities* (which entities interact with which, under what conditions, and how entity properties change as the result of interactions); and
- a *dynamic*, which specifies the order in which entity interactions take place.

The ontology is *minimal* if each specified entity and property type and interaction modality is causally efficacious – and, of course, no other causally efficacious entity slips into the stories as they are recounted.⁶ Our ontology for innovation includes such entities as agent-artifact space, market systems, competence networks, scaffolding structures, and generative relationships. I will say something about some of these later in the chapter; for an introduction to all of them, see Lane and Maxfield (2005).

Building a theory of innovation and telling stories about innovation episodes is a kind of dialogue, in which the theory informs the construction of the narrative, and the resulting narrative tests the adequacy of the theory to generate deep insights into the episode and its attendant phenomena – and when it reveals gaps and imprecision in the theory, prompts the theorist to revise it.⁷

There is another kind of dialogue that can be useful: the dialogue between theory and mathematical models. While a theory specifies the dynamics of organizational emergence and transformation qualitatively, it is difficult to rely on our own experience and research into concrete episodes to gain a deep understanding of the dynamics of complex systems. In any given story, much more is going on than what our theory picks out as important: how can we know that particular kinds of emergent properties really depend just on the entities and interaction modalities the theory postulates? Here, mathematical models that provide abstract representations of subsets of the theory's ontology can be very useful, since if such models exhibit analogous emergent properties, they must perforce depend just on the elements and relations incorporated in the model – and nothing else. Thus, assuming that the analogy between the theory ontology as instantiated in the narrative and in the model is sufficiently convincing, the mathematical demonstration of emergent dynamics in the model enhances the causal convincingness of the analogous emergent dynamics in the narrative. In the course of developing and

⁶ I have used the term *causally* (efficacious or convincing) rather cavalierly: efficacious or convincing *for whom*? We have come to believe that there is no dodging the fact that for any theory this question has to be raised – and answered, by specifying a particular community that uses the theory in question to tell stories among themselves about the phenomena in which they are interested. There are lots of different ways to tell stories about particular episodes in the history of innovation. Each of them will be based, implicitly or explicitly, on some ontology; a sufficiently abstract form of ontology that allows one to tell lots of stories about other episodes of artifact innovation would count as a theory, perhaps alternative to the one we have developed. The power of these theories can be assessed by how *deeply* (in any given episode), *widely* (over a set of episodes that share the phenomenon of theoretical interest, in this case artifact innovation as we have defined it, but differ with respect to other characteristics, like time, space, artifact type) and *convincingly* (within the community of reference) are the stories constructed with their ontologies. Related ideas about what constitutes a theory for understanding social phenomena are developed in much more depth and philosophical precision in Hacking (2002) and Davidson (2001).

⁷ Examples of dialogues between historical narratives and various aspects of our theory include Lane and Maxfield (1997, 2005, 2009), Russo (2000), Bonifati (2008), Rossi et al. (2009).

deepening our theory of innovation, we have constructed agent-based models that provide insight into the dynamics associated with *generative relationships* and *exaptive bootstrapping*, two theoretical concepts discussed in the following sections.⁸

4. Exaptive bootstrapping and innovation cascades

One new thing leads to another: innovations occur in cascades, and involve transformations not only in artifact types, but in organizational forms and attributions as well. In this section, I sketch the theory of exaptive bootstrapping, which explains how such cascades happen. The theory, based on organization thinking, provides a qualitative description of a positive feedback dynamic in agent-artifact space, which accounts for the explosive growth that characterizes human sociocultural change, particularly over the past several centuries.

I begin by distinguishing between two different kinds of invention activities: those that are intended to deliver an existing functionality “better-faster-cheaper” than the artifacts that currently do so, and those that are designed to deliver *new* kinds of functionality. An innovation cascade can be initiated by either type of invention, and in any cascade both types are present.

For example, the invention of printing by movable type was a “better-faster-cheaper” innovation: Gutenberg’s workshop figured out how to produce multiple copies of a manuscript more quickly and cheaply than could be done by hand-copying. But almost immediately, the first printing enterprise, headed by Gutenberg’s ex-partner Fust and ex-assistant Schoeffer, had to solve a series of organizational and business problems that required new attributions of functionality: for *agents*, who had to pay up front for the paper for over a hundred copies (soon hundreds to several thousands) of a text, before selling any of them, and needed to work out new techniques for financing, selecting, marketing and selling their products; and for *artifacts* – what kinds of texts to print, and how to present them, in order to attract new customers who could not afford hand-copied manuscripts, but could pay enough for the right kind of printed book. And the solutions that the early book producers developed to these problems established new kinds of texts (and hence “reading functionalities”) that in turn induced the development of better-faster-cheaper improvements and novelties in both the physical and informational forms of books.

Though typically innovation cascades contain both types of innovation, we claim that the positive feedback dynamic depends on the existence of the second kind – in particular, on the role of new attributions of functionality in bringing these about. The theory of exaptive bootstrapping posits the following stages for the positive feedback dynamic:

1. New artifact types are designed to achieve some particular attribution of functionality.
2. Organizational transformations are constructed to proliferate the use of tokens of the new type.

⁸ See Lane et al. (2004), Villani et al. (2007), Serra et al. (2009) and Villani et al. (2009) for details.

3. Novel patterns of human interaction emerge around these artifacts in use.
4. New attributions of functionality are generated – by participants or observers – to describe what the participants in these interactions are obtaining or might obtain from them.
5. New artifacts are conceived and designed to instantiate the new attributed functionality.

Since the fifth stage concludes where the first begins, we have a *bootstrapping* dynamic that can produce cascades of changes in agent-artifact space. These cascades inextricably link innovations in artifacts, in organizational structure, and in attributions about artifact and organizational functionality.

Exaptation is the taking on of *new* functionality by *existing* structure.⁹ It happens between the third and the fourth stage in this process, whereby new attributions of functionality arise from observing patterns of interaction among agents and already existing artifacts. The idea here is that artifacts gain their meaning through use, and not all the possible meanings that can arise when agents begin to incorporate new artifacts in patterns of use could have been anticipated by the designers and producers of those artifacts: the combinatorial possibilities are simply too vast when a variety of different agents intent on carrying out a variety of different tasks have available a variety of different artifacts to use together with the new ones – not to mention that the designers and producers do not share the experiential base and the attribution space of all the agents that will use the artifact they produce, in ways that depend on their experience and attributions, not those of the artifact's designers and producers! Meaning in use is one thing – the *recognition* that that meaning might represent a functional novelty is another. For this to happen, some participants in (or observers of) these patterns of interaction must come to understand that something more is being delivered – or could be delivered, with suitable modifications – to some class of agents (perhaps, but not necessarily, including themselves) other than what the participants were thinking to obtain through the interactions in which they were engaging – and that these agents might come to value this new functionality. Thus, the generation of new attributions of functionality is grounded in an *exaptation*: from the interactions between existing structures (agents and artifacts), new functionality emerges. It may then become recognized by appropriately situated and motivated agents, and (re)cognized as a new attribution of artifact functionality.

To illustrate the stages described, consider the following example. In this example, stage 1 corresponds to the *printed book*, and stage 5 to the *printed advertisement*. The linking stages can be summarized as follows. Before printing, almost all manuscripts were produced in response to orders from a commissioning agent. Not surprisingly, this was initially the case also for the first printing firm, established in Mainz using the printing technology developed by Gutenberg and his co-workers, which was headed by the

⁹ For introductions to and references about exaptation, see Gould (2002, chapter 11), in the biological context, and Villani et al. (2007, plus discussion), in the sociocultural context.

financier Johann Fust and the printer Peter Schoeffer.¹⁰ Fust and Schoeffer had one important client, the archdiocese of Mainz, which commissioned many books from them including religious and liturgical works, references in canon law, and texts for the new humanistic school curriculum in which their clerical workers were trained. Fust and Schoeffer realized early on that they could probably find purchasers for additional copies of these books. They faced the problem of how to reach these potential purchasers and convince them to buy the printed books. One organizational solution to this problem that the firm explored was to hire traveling representatives, which constituted stage 2 of the exaptive bootstrapping cycle. These representatives of course visited fairs and festivals, but they also stopped at towns along their route. When they did so, they would have to make known to potential purchasers their whereabouts and their wares – stage 3. One approach that the firm took to this problem was exapted from their primary ongoing activity, in stage 4: they conceived the idea of using printing, the same technology they employed to produce their wares, to enhance distribution. The new artifact type they developed (stage 5) was the printed advertisement. Their earliest surviving printed advertisement dates from 1469. It is a one page broadside, which begins as follows: “Those who wish to purchase for themselves the books listed hereafter, which have been edited with the greatest care and which are set in the same Mainz printing type as this announcement ... are invited to come to the dwelling place written in below” (quoted in Lehmann-Haupt, 1950, p. 86). Thus, the advertisement attests not only to the *nature* of the wares (the list of books that it provided), but also to their *quality* (the “same Mainz printing type as this announcement”). Note that the name of the inn where the representative could be found had to be hand-written, as it changed with time and town. The printed advertisement instantiates the new attribution of functionality: the possibility of mass-circulating information about a product to recruit potential purchasers. Other instantiations of this attribution, for other classes of products, followed, and the circulation of printed catalogues soon became an important means of disseminating product information and organizing exchange activities.

Innovation cascades involve many cycles of the exaptive bootstrapping process. In addition, these cascades typically also include processes that are purely *adaptive*: given an attribution of functionality and an artifact that realizes it, apply a known technology to improve the artifact or its method of production to render it better (according to the values associated with the given attribution of functionality), faster or cheaper. Such processes do not require the generation of new attributions of functionality. Note, though, that better-faster-cheaper invention is not necessarily purely adaptive: when observed close up, they may require new attributions of functionality as well. For example, Gutenberg had to exapt a variety of techniques he had learned as a jeweler in quite different contexts, even with different materials, for the new functionality of type-casting. In such cases, not only the exaptation of new attributions of functionality, but also organizational transformations like those in stage 2 are required, for example in assembling a team of agents that collectively embodies the different competences necessary to achieve a complex better-faster-cheaper invention – and in developing the

¹⁰ Gutenberg himself was an early example of an inventor who failed to make the transition to innovating entrepreneur. See Lehmann-Haupt (1950) for an account of the history of the interactions among Gutenberg, Fust and Schoeffer.

procedures whereby this team can sufficiently align their directedness and then attributions about each other and the artifacts with which and towards which they work to accomplish what they have come to intend to do together.

5. Generative relationships: the locus of new attributions

According to the previous section, the most important cognitive process in innovation is the generation of new attributions. Similarly, the most important communication processes involve the aligning of attributions among agents, otherwise the processes of recruitment, differentiation and coordination that underlie the collective action necessary to transform new attributions into new artifacts into new patterns of interaction cannot take place. As we saw, innovation often begins with a new attribution of functionality – an idea for a kind of activity in which people may wish to engage that can be realized by means of an artifact. Moreover, virtually all constructive innovation processes require new attributions of identity for the new entities in agent-artifact space that these processes generate. Since identity is relational, the construction of new entities that become incorporated in patterns of activity with previously existing entities generally requires modifications in the attributions of identity for these entities as well.

These new attributions arise in the context of a particular kind of relationship among agents, which we call *generative*. While the kind of ontological uncertainty that typically shrouds innovation processes makes it impossible to predict in detail what sorts of new attributions a relationship may generate, it still may be possible for agents to assess the *generative potential* of a relationship. This potential depends on five characteristics of the agents in the relationship and their modes of interaction with one another, and agents may not only infer the degree of these characteristics through their interactions, but may also act in such a way to increase the relationship's generative potential. These characteristics are: *aligned directedness*, *heterogeneity*, *mutual directedness*, *appropriate permissions*, and *action opportunities* (Lane and Maxfield 1997, 2005).

In zones of agent-artifact space that are undergoing rapid change, identities change, and agents need to track these changes carefully in their attributions of identity of the significant agents and artifacts in their world. The process of monitoring and interpreting identities requires discourse with others, since any agent has only a partial and restricted view of what others do – never mind how they interpret what they are doing. This discourse is channeled through the agents' informational and interpretative social networks. Generative relationships emerge from these networks. These relationships may link actors who work for the same firm, groups of actors from more than one organization engaged in joint projects, or agents working together under the auspices of a market system scaffolding structure. The important point is that in generative relationships, agents have *aligned directedness* – that is, their interactions are focused around achieving similar transformations in the same zone of agent-artifact space – and they are characterized by significant *heterogeneity*. Unlike social actors who may prefer the company of like-minded others, innovative agents have to seek out and build strong relationships with others that differ substantially from them in some important respects – even if they hope to construct eventually a set of attributions about artifact meaning and

agent roles sufficiently aligned to support a stable market system around the artifact family they are trying to bring into being.

Whatever the kind of heterogeneity that attracts the agents into working together – differences in competence, in position within social or economic networks, in access to particular resources – these agents are bound to have different attributions about important artifacts and agents in their common world, differences that reflect the heterogeneity of their past experiences. Attributions are not directly observable – even less so than the other sources of heterogeneity mentioned above. As agents begin to interact to establish patterns of joint action, attributional differences among them may surface – typically, in the form of utterances or actions that cannot be coherently interpreted from the point of view of the attributions the listener has assigned to the agents or artifacts to which the utterance refers or the action is targeted.

Agents may respond in several different ways to their discovery of attributional difference. They might confuse their own attributions with “reality” and decide that the other is either ignorant or less intelligent – a reaction that can be encouraged by attributions about social or intellectual differences between discourse participants. This mode of reacting to differences undermines *mutual directedness*, the “attraction” towards one another that induces partners to enter into and continue joint interactions, another of the determining characteristics of generative potential – and thus typically prevents the relationship from further development, never mind generating anything! A second reaction mode is to step carefully around any attributional differences that may surface. This reaction is more politic and may permit the relationship to continue, and it may even enhance the generative potential of the relationship if a particular attributional difference is so tied to the identity of one or the other agent that its exploration could only lead to the termination of the relationship. However, if all differences are handled in this way, the participants in the relationship do not have the appropriate *permissions* (what they can say to whom, about what, in which illocutionary mode) to provide generative potential to the relationship. Some permissions are explicit, others implicit; some derive through organizational hierarchies, from agents who have permissions that allow them to grant permissions (and deny them) to other agents, while others emerge from the social interactions in which agents are embedded; some are arrogated by agents for themselves, but then may become the object of contestation and negotiation among agents – negotiations channeled by other sets of permissions that characterize organizations in which the negotiations are carried out, from court-rooms to legislative bodies to trade associations to standards bodies. Analyzing permissions structures is an essential element of organizational thinking – and determining which permissions are available to interacting agents essential for establishing the generative potential of the relationship among these agents (Lane and Maxfield, 2005, 2009).

If the relationship really has generative potential, then participants can respond to attributional differences when they surface by exploring them, through extended discourse. As discourse expands around the discovered difference, *semantic uncertainty* (that is, uncertainty about what particular propositions mean) typically initially *increases* for all participants, as more and more of their attributions are linked to those for which

the differences were first discovered – and differences among these too become revealed. What such a process may lead to is cascades of change in each participant’s attribution set – that is, their representations of the structure of agent-artifact space. It is this process that leads to new attributions. Opening up attributions for discussion generally is not resolved through anything as simple as replacement (that is, accepting another’s attribution in place of one’s own) or combination (that is, merging through Boolean operations that put together one’s own attributions with those of another). Rather, from what others reveal about their attributions, one may realize new *dimensions* for evaluating aspects of identity – and these new dimensions may lead to new possibilities for relations among different attributions, which imply shifts in the attributions themselves. But given the differences in starting points, and the difference in interpretations of the added dimensions, there is no reason to think that attributions of different agents need come “closer together” through this process, never mind come into alignment. Of course, talk is not enough: the participants in a generative relationship must also have appropriate *action opportunities*: the possibility to engage with one another in interactions that result in transformations not just in their own attributions, but in the structure of agent-artifact space.

To illustrate the concept of generative relationships, we return to the early days of printing. The career of the great Venetian printer Aldo Manuzio is marked by his capacity to enter into and sustain generative relationships.¹¹ Manuzio was an enthusiastic humanist knowledgeable in Latin, Greek and Hebrew, employed as a private tutor in the household of the Pio family, lords of Carpi, who were cousins of one of the greatest (and highest-born) humanist scholars, Pico della Mirandola. Around 1490, when he was already 40 years old, Manuzio conceived a project: to exploit the new technology of print to increase the diffusion and appreciation of Manuzio’s beloved Greek philosophy and science. By 1490, printing had expanded well beyond its Rhineland birthplace, and an international market system in printed books was rapidly taking shape, with production centered in Venice (where 1/7 of all 15th century European editions were published!) and the principal scaffolding structure (then as now, at least in Europe) the annual Frankfurt book fair. Most texts were in Latin, with an increasing number in local vernaculars; Italian printers had published a few Greek works, mostly grammars and other instructional material. Medieval copyists in Western Europe produced manuscripts of Greek writers only in Latin translations (in general, from Arabic translations of the original Greek works!). Particularly after the fall of Constantinople to the Turks in 1453, many Greek scholars fled to the West, bringing manuscripts with them. Some of these scholars set up schools to teach their language and literature to students already primed to learn them from their exposure to the work of the first several generations of humanists. For Manuzio, there was already a substantial cultured public ready and eager to benefit from the wisdom of the Greeks, and he wanted to provide this public with philologically correct and readily available texts. Print was the ideal medium for accomplishing this project, and the distribution channels associated with the emerging market system in printed books provided the possibility of reaching potential readers throughout Western Europe.

¹¹ For Manuzio, see for example Lowry (1979), Dionisotti (1995), Marcon and Zorzi (1994), and Zeidberg (1998), Richardson (1994).

So, supported morally and financially by his devoted Pio students, Manuzio moved to Venice and began to figure out what he needed to know to carry out his project. Four years later, he had succeeded in putting together a partnership and a network of collaborators. One of Manuzio's partners was Andrea Torresani, one of the first Italians to enter the print trade. Torresani was not a cultured man, who certainly knew no Greek, but he had considerable practical experience in printing and bookselling. In the company, he primarily concerned himself with the latter activity – Aldo himself, after he learned the trade from Torresani, ran the print shop, in addition to what we would now call his work as publisher: that is, deciding what texts to print, dealing with authors or editors and illustrators, determining the form of the book and so forth. By the 1490's, shrewd printers like Torresani realized that the constant reprinting of a rather small number of texts, which characterized the first several decades of the emerging industry, could not continue, were particular firms and the industry as a whole to continue to grow. He probably was convinced by Manuzio's argument that a sufficient number of the readers of the classical and humanist Latin texts currently in publication (by many different printing houses) had enough Greek to welcome the kind of text Manuzio had in mind to publish, works in philosophy and science most of which had not yet appeared even in Latin translation.

The group's other partner was a Venetian nobleman, Pierfrancesco Barberigo, son of a doge and nephew of the current doge. Undoubtedly the Pio connection was crucial to Aldo's success in recruiting such a well-positioned member of Venetian society into his enterprise. While Barberigo was mainly an investor, he also played an important role in helping the Aldine press deal with political issues, like securing various patents and copyrights from the Venetian government, and financial ties with banks.

The partnership functioned very well, surviving several crises in the Aldine press' own affairs, the printing business in general, and Venetian politics. In 1505, Aldo married Torresani's daughter, and the families set up a joint household, over the printing shop. The Barberigo family continued to participate in the press and draw their share of the profits after Pierfrancesco's death.

Even this brief description suffices to illustrate both the heterogeneity and the aligned directedness of this partnership, which became a generative relationship: note that the alignment is towards what we might call the development of a particular zone in agent-artifact space, but undoubtedly did not extend to a shared vision of the importance of publishing Greek works to deepen the understanding of the world on the part of a cultural elite! (In fact, as we will see, the practical bookseller Torresani and the profit-seeking Barberigo family pushed Manuzio to change direction, as the Greek books they produced sold considerably more slowly than they had initially hoped.)

Initially, the network of collaborators of the Aldine press consisted of eminent Greek scholars, who edited the works that Aldo published; collectors of manuscripts, like the nobleman Bernardo Bembo, who provided the texts with which Aldo and his editors worked; and a group of avid Venetian students of Greek, who helped provide Aldo with a

sounding-board for ideas on which texts to publish. The latter group organized itself in 1500, under Aldo's leadership, as the "New Academy", whose members agreed to speak Greek at their meetings, where they were to discuss themes of common interest.

In 1495, the Aldine press began publishing, with a grammar by the most eminent Greek immigrant currently teaching in Italy, Constantine Lascaris, and the first volume of its most important and ambitious Greek language project, the collected works of Aristotle. Aldo obtained the Lascaris' text in manuscript from Pietro Bembo, the young son of Bernardo, who had just returned from two years of study under Lascaris' direction in Messina.¹² For centuries, male members of the Venetian patriciate chose one (or sometimes more) of three possible careers: public service in the Venetian administration (or navy), commerce, or the church, a choice usually possible only for younger sons. Pietro Bembo's father had been one of the first generation of Venetian patricians to embrace humanism while studying at the University of Padua, and throughout his long and distinguished career as a diplomat and administrator¹³ he collected manuscripts and developed friendships with leading scholars. Growing up in this cultivated household, young Pietro early developed strong scholarly and literary inclinations. When he returned from Messina, he wrote a short work in elegant Latin, *De Aetna*, recounting some of his experiences to his father, which was published, probably as a return favor for the Lascaris manuscript and Bernardo's cooperation, by Aldo in 1495.¹⁴ By the time he finished his studies at Padua, he was not attracted either by public service or commerce. He spent several years at the court of the Este family in Ferrara, consorting with such literary luminaries there as Ariosto, and he began himself to compose works in the vernacular (including the beginning of a dialogue on romantic love, *Gli Asolani*, eventually published by Aldo in 1505). More and more, he dedicated himself to literature, and so he increasingly departed from the life-ways his society considered appropriate for a Venetian patrician. Both Aldo and Bembo, starting from very different positions in Quattrocento Italy, were constructing new kinds of identities as the new Cinquecento dawned.

By 1500, it was becoming clear to the partners in the Aldine press that the magnificent Greek folio volumes they were producing were selling too slowly to justify the investments they required. Until then, Aldo had yet to enter the overcrowded but high-volume market of Latin classics. As he considered alternative new publication projects, he began to reflect on a new way to present these books. In general, the classics had been published as weighty tomes, usually folios or quartos, smothered in commentary to help the reader understand the text. Manuzio, though, envisioned a particular kind of reader: active and cultivated men, like Bernardo Bembo, who might enjoy reading for their pleasure and edification whenever they had a spare moment from their labors, and who didn't need to be led by the hand by an intrusive editor's selected commentaries, but would prefer direct, "personal" interaction with the ancient authors. Such men would demand a high level of rigorous philology in the preparation of the text, with perhaps an

¹² For Bembo, see Dionisotti (2002), Kidwell (2004), Richardson (1994).

¹³ While serving as Venetian rettore in Ravenna, he commissioned the beautiful monument that marks the tomb of Dante in that city.

¹⁴ The press's first publication in Latin.

introduction explaining issues encountered in choosing between variant manuscripts, but no commentaries. Without commentaries, the texts would be considerably shorter, and it might be feasible to bring out smaller books that the reader could carry with him on his travels, in his saddlebags or even in his pockets. So Aldo had the idea of publishing a series of Latin books in ottavo, designed for easy readability, printed in a new kind of font, in italics, which he thought was both more pleasing to the eye and more *intimate* than the standard fonts used heretofore.

Aldo discussed this idea with his circle of friends and collaborators, among which was Pietro Bembo. Bembo was attracted to Manuzio's project, so compatible with his own view of the meaning and value of literature, but he urged Aldo to go a step further, by including "classics" in the vernacular in the new series: to Bembo, Aldo's idea represented a great opportunity to boost the status of *vernacular* literature, by associating it with the aura of cultivation and gentlemanly entertainment that Aldo's format was designed to confer. Aldo himself had little interest in vernacular literature: before 1500, he had published only two: one a religious work of Saint Catherine of Siena, and the other the bizarre *Hypnerotomachia Polifili*, neither then nor ever considered a "classic" (although the Aldine edition is regarded as one of the most beautifully illustrated books ever published).¹⁵ However, Aldo accepted Bembo's advice, and Bembo himself edited the first of these (and the third overall in the series, after a volume of Virgil and one of Horace): Petrarch's *Cose Volgari* of 1501. Bembo's role as editor was not explicitly acknowledged in the book, since he was not yet ready to embrace fully a role absolutely extraneous to the Venetian patrician way of life: a professional man of letters, whatever that might mean in 1500.

As editor of the Petrarch text, Bembo introduced a number of important innovations, beyond the ottavo form and the italic font. To implement Aldo's vision of easy readability, the book introduced several novel punctuation marks, including the apostrophe to indicate contractions and the comma. In addition, Bembo applied philological principles in an attempt to reconstruct Petrarch's original text (his principal manuscript source was in Petrarch's own hand, from Bernardo's collection): before this, editors felt free to change words to conform to current usage or different vernacular dialects – or even to "clarify" meaning of difficult passages. Finally, and most importantly for the future, Bembo's introduction defended his editorial practice, by developing an evolutionary theory of language, according to which languages "mature" to a certain point of perfection and then begin to decline – and he argued that the Tuscan dialect reached its apex in the age of Petrarch (for poetry; he later added Boccaccio for prose), which was the language he sought to uncover and which he proposed as a model for all future literature in vernacular. In a sense, this introduction is the first formal proposal of the vernacular as a literary language, with its own rules and literary history – an argument to which Bembo returned in 1525, with the publication of *Prosa della volgar lingua*, which many consider the formative work for the construction of an Italian language.

¹⁵ It remains a mystery why Aldo published this work, so different from anything else released from his press. There are indications that he wished to dissociate himself from the book, despite its beauty.

In their work in conceiving and producing the new series, Bembo and Aldo formed a generative relationship,¹⁶ and the attributions and artifacts to which this relationship gave rise have an importance that is difficult to overestimate. Their Petrarch volume was the first ottavo in vernacular published in Venice – but not the last, as Figure 1 below shows. Bembo’s introduction sparked an intense debate about the vernacular as a literary language, to which such luminaries as Machiavelli and Castiglione contributed with alternative proposals, but by the 1530’s Bembo’s ideas had swept the field. Indeed, all vernacular writers understood that “good literature” requires a language with an established lexicon and structured syntactical rules, which provide the background constraints on which their own particular usage patterns can generate an emergent “style”. That Bembo’s vision of what that lexicon and syntax should be would become the canonical one was by no means a foregone conclusion, but the immense success of the Petrarch volume was an important step along that path. Moreover, Bembo’s punctuation aids, along with his “de-latinized” vocabulary and spelling, also triumphed. More important, the new form and format of the Aldine series, especially in its vernacular volumes, helped generate a larger reading public, who began to read in new ways appropriate to reading as entertainment and past-time, rather than reading as serious study in a contemplative space.

This enlargement of the reading public was very much helped along by an exaptation from the Aldine innovation in form and font. The first volumes of the series, released in 1501, were a big success, and some Lyonnais printers quickly provided another interpretation of ottavo in italics: the italic font allowed more characters per line than a standard font with the same legibility, and the smaller ottavo format permitted more characters per area of paper used. So the new format could be exploited to produce *cheaper* books – an idea quite foreign to Aldo’s way of thinking about books! They immediately copied Aldo’s work, squeezing more lines per page than his aesthetics permitted, using inferior paper, inks and italic characters – but producing books with record low cost, making them accessible to a larger potential public. A new innovation cascade was underway, with new kinds of texts produced and published to satisfying the emerging tastes of an expanding reading public. By 1540, a new role had come into being: the professional author, who his (usually precarious) living by providing these texts,¹⁷ working closely with increasingly entrepreneurial publishers (another new role!) who were particularly apt in anticipating the kinds of texts that would both satisfy some existing set of readers and recruit new ones. It was these new kinds of texts and new readers that account for the explosion of vernacular ottavos between 1500 and 1545 portrayed in Figure 1:¹⁸ the tradesmen who pored over vernacular ottavo “how-to” books, the professional people who read the letter collections¹⁹ that they adopted as

¹⁶ I leave it as an exercise to the reader to verify the generative potential conditions!

¹⁷ See Richardson (1999), Grendler (1969) and Larivaille (1997).

¹⁸ Which may resemble the sort of S-shaped curves that innovation “diffusion” theorists love to model – but which is due to a constructive dynamics, featuring cascades of innovations in artifact types, agent roles, attributions and the organization of the market system around books, as far from a passive “diffusion” dynamics as one could well imagine!

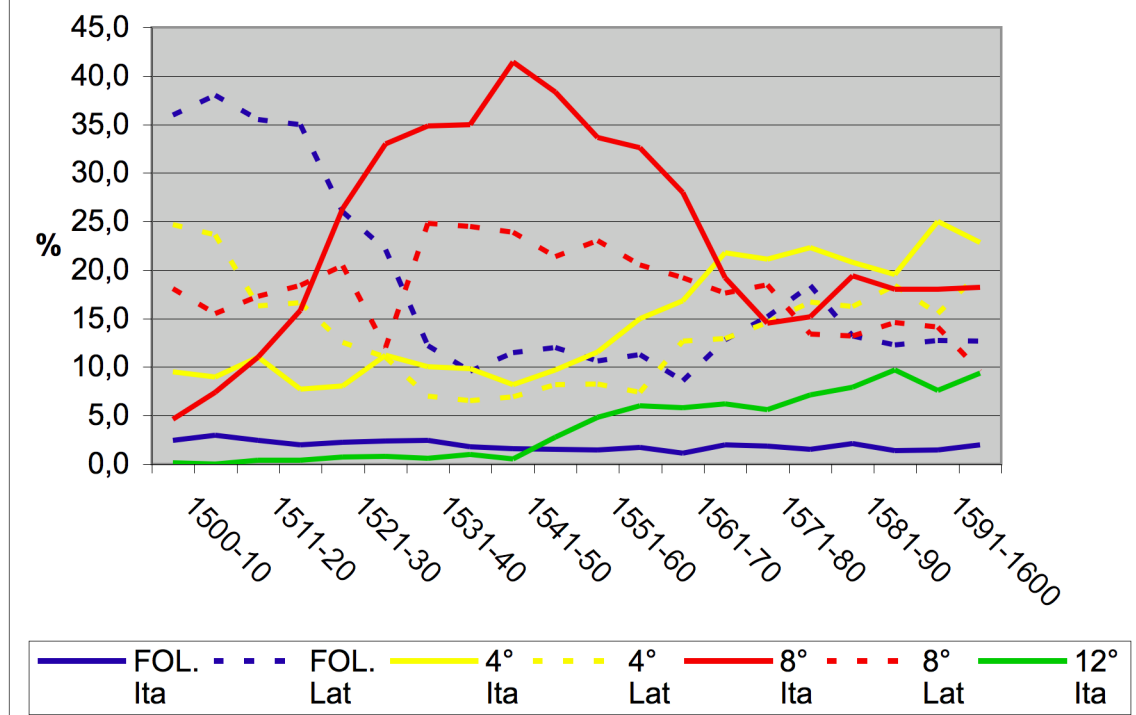
¹⁹ Pioneered by Aretino, who had them published mainly to blackmail leading political figures to induce him to sing their praises instead of making them the targets of his withering sarcasm; while his clever publisher Marcolini brought out volumes of Aretino’s letters in ottavo because he had intuited just how big

models for their own correspondence, not to mention all those who were entranced by the first “puzzle books”, or were entertained and informed by expositions of the wonders of nature, including guides to self-medication for all sorts of common afflictions. Because the new ottavos in vernacular were highly portable, increasingly cheap, with contents appealing to an ever more popular reading public, new distribution channels were initiated to carry them to parts of the public off the beaten track: in particular, the male populations of whole mountain villages began to be recruited by publishers to carry their ware into smaller remote population centers, and the book peddler began to become a familiar figure throughout the Western European countryside. And because the volumes these peddlers sold were so small, when necessary they could also be carried surreptitiously, hidden in clothing or concealed under other kinds of goods: ideal for some of these peddlers to smuggle Protestant texts from Germany and Switzerland into French and Italian territories, whose rulers were intent on stamping out the new heresies in their lands.

Note how different is this sort of innovation cascade from another concept in the innovation literature that links different inventions together, the technological trajectory. The latter is characterized by predictability: the inventions all do the same kind of thing, pushing further along a well-demarcated and collectively recognized trajectory in artifact space. Of course, agents are necessary to work out the technological details that join one point in the trajectory with another, but the trajectory itself appears as some sort of natural kind. The trajectory of changes in the innovation cascade that follow from Manuzio and Bembo’s new attributions and the artifact they constructed to instantiate it is anything but linear and predictable. It passes through changes in artifact type, attributions, agent organization, impinges on technology, aesthetics, social organization, politics – each change contributing as preconditions but hardly determining those that follow, each of which is constructed through the interactions of many different kinds of agents, with different intentions, creating through their interactions new emergent patterns and structures that no-one could have foreseen, but which retrospectively had to be incorporated into new attributions of agents seeking to make sense of their world in order to act to change it. The trajectory of an innovation cascade is an historical process, no natural kind, and can be understood only from an historical perspective, based on some set of ontological commitments about the kinds of interacting entities, interaction modalities and ensuing dynamics that provide the framework in which the trajectory’s emergence can be narrated.

a market there might be for gossip about the doings of rich and the famous.

Figure 1: the Venetian book, format and language



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