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System Emergence, System Effects
A Formation Story of Air Traffic Control

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Abstract

This paper takes up the issue of historical narratives that trace the emergence, persistence, and change of new forms of social organization. Hirschman and Reed argue that these "formation stories" are not simply descriptive but are fundamentally causal, "providing the historical empirical boundaries for the functioning of forcing-cause accounts" that are more typical of historical sociology (2014: 259-282). Drawing from an historical ethnography of four facilities in the air traffic control system that locates the fieldwork chapters between system history and the present, I give an overview of the emergence of this socio-technical system, its transformation, and system effects on controllers and their work over 12 decades. The inductive analysis showed an incremental process marked by eras indicating variation in developments over time: the dominant actors driving the system - individuals, organizations, or technology – changed; development was uneven, and following Abbott, turning points across the life course were diffuse. Studies in History of Technology became essential. Across all eras were five patterns showing ongoing, overlapping processes that shaped the system, its technologies, and its effects: System Emergence, Institutionalization and Elaboration; Historical Contingency; The Changing Nature of Work; Precedent and Innovation; and Shifting Boundaries in the Sky and on the Ground. The conclusion addresses how this case both conforms to and deviates from the typical event history analysis in historical sociology, the difference and similarities in the patterns found, and how analyzing formation stories as causal accounts can build the analytic and theoretical repertoires of historical sociology, history of technology, and organization theory.

How does history affect the present? This paper takes up this inquiry, identifying the main patterns found in the emergence, development, and operation of air traffic control as a socio-technical system, from the turn of 19th century to the turn of the 20th century, when I entered the field. It is drawn from an historical ethnography that incorporates mixed methods, primarily ethnography in a study of four air traffic control facilities, chosen to represent the diversity of work that controllers do. A novel approach for ethnography, it brackets the empirical fieldwork between the system history and the present. This approach became essential. The patterns that I saw in the facilities were there long before I came. The organization, the occupation, and controllers' experiences at that time had their roots in events in the past. Factors external to the air traffic control system – economic fluctuations, war, political administrations, technological innovation, catastrophic air crashes, for example - shaped the system and have remained continuing influences upon it, affecting its structures, processes, and the development of its technologies of coordination and control at the time of the field work and today.

Situating the ethnographic research between the social-technical system history and the present reveals how history acts on a place and its people. We can see how sequences of events unfold, showing the causal links between the past, the moment of research intervention, and what happens to the patterns and the people after we depart. Doing so shows system emergence and the transformation of its structure over time, allowing us to consider both change and persistence of patterns historically. Simultaneously taking a situated action approach shows the dynamics of system effects: how external events that shaped and reshaped the system, which in turn affected controllers and their work from the earliest years of the profession on. Far from a top-down model, this history displays the agency of actors, internal and external to the system. At the turn of the 20th century, we can see how the old mixed with the new, affecting how both system and controllers worked, thereby explaining how they did the impossible on September 11 and how they transformed the system during the year after. Then, the last chapter picks up the narrative thread of time, illuminating the continuities and differences between then and now. This strategy is essential for understanding how this error-reducing system operates today and considering the broader question of automation and the human-technology interface.

Causal explanations of historical events, institutions, and outcomes are best understood by narratives – story-like explanations - that capture the sequential unfolding of events in and over time, showing the interaction of structures and social actions that drive change.[1] Crucially, *when* an action happens – its order in a sequence of occurrences – is more important than *that* it happens. And *how* things happen is the explanation for *why* things happen.[2] These historical sequences have no predictable outcome or pattern. They are marked by contingency and unique combinations of causes coming together in different times and places.[3] Some historical narratives are path dependent, meaning they are comprised of sequences of occurrences at one point in time that lead inexorably toward a particular outcome at another point of time in the future. Other sequences are marked by their unpredictability and the unanticipated consequences of events, having many turning points – even reversals, while still others never materialize into anything permanent, having no lasting social impact, or disappearing.

Time and timing make each case unique. However, despite this diversity, they tend to have two characteristics in common. First, the sequential unfolding, ordering, and historical movement of events and social actors through time has explanatory power that helps us understand the relationship between the past and some determined present. Second, the explanation of each case has identifiable patterns that stand out across temporal settings. To sensitize readers to the patterns and variations in the narrative history that follows, here is an overview of the major ones that typified the air traffic control system emergence, transformations, and its effects on controllers and their work over time. For this analysis, I inductively created the narrative history and analysis based on my research experience with historical chronologies (*Uncoupling: Turning Points in Intimate Relationships*, 1986; *The Challenger Launch Decision*, 1996) and my knowledge of organization theory and science and technology studies. When this phase of the analysis was complete, I turned to historical sociology and history of technology. For more detail on my methods, see note.[4]

System Emergence, System Effects: Patterns and Variations in the Life Course

The works of historical sociology confirmed many of the patterns I found. System development was marked by path dependence, sequences of events, turning points, historic contingency, and multiple patterns of causal links. Also, a focus on problem solving explained the causal connections across temporal settings by showing how social actors make use of the past to influence the present and future.[5] Even in the earliest moments of system development, this history reveals both the creative and constraining actions that problem solving individual and organizational actors provided, slowing or speeding social transformation. However, the air traffic control system is different from the subject matter of many historical sociologists. They tend to study causal processes in nation states that lead to some major event or disruption resulting in a large-scale social transformations and reorganization.[6] Although nation states and air traffic control are both systems, this history shows air traffic control had an incremental development over the life course. True, it has experienced several major shocks originating both outside and inside the system: the strike and firing of controllers in 1981 and the catastrophic events of September 11th , the latter resulting in sudden disruptions and extensive major changes to the system. But even changes from these most extreme shocks were absorbed by the existing structure, rather than eliminating or destroying parts of it, or changing its basic direction.

This narrative history traces the life course of a large scale social-technical system that remained relatively stable across time. Rather than transformation of a social kind already in existence, it traces the formation of a novel social entity: how and why it came to have the shape, vulnerabilities, and capacities it has.[7] A formation story is one that follows the social process by which a social entity comes into being, then, if it persists, becomes stable enough to have causal effects on the environment and the individuals within it. [8] Thus, it captures both system emergence (being subject to external forces) and system effects (becomes a force in itself). A central pattern in a formation story is the importance of both socio-technical assemblages and actors' own understanding of the social world. These characteristics resonate with research in science and technology studies and the history of technology.[9]

In particular, Hughes established the study of technical systems as a new direction for historians of technology.[10] Breaking with the tradition of studying the development of a single invention, he found that a variety of social actors - professionals engineers, managers, scientists - and heterogeneous organizations became "system builders": knowledge, physical artifacts, individuals, groups, and institutions interacted to solve problems or to fulfill goals.[11] Confirming Hughes, the air traffic control system was built and operated by an assemblage of multiple heterogeneous actors. Not only were they individual social actors who actively problem solved in their professional roles, but there were “regimes of problem solvers” (changing political administrations),[12] and still others – both organizations and individuals - who by simply acting in their own interests, unintentionally spurred advances and/or detours in system development. Finally, in the absence of a major event or disruption that was a turning point, or “the” turning point, this history is marked by four eras that show patterns and the variations in system emergence and effects over time, and a fifth, the transitional period at the turn of the century showing the continuities between the past with the ongoing history-in-progress in the facilities when I entered the field.

Each era is comprised of a sequence of unique events that constitute its essence, distinguishing it from the others. In common the social and technical are intertwined in each; similarly, the past is intertwined with each era’s present. Although I necessarily condense history, events are sufficiently varied and detailed to surface incidents that show how small events can have seemingly large consequences.[13] Moreover, the details often correct well-known aspects of collective memory. So, for example, Charles Lindbergh’s record breaking 1927 New York to Paris flight became the iconic representation of the successful achievements of American air flight during the twenties, but the less-remembered 1929 Women’s Air Derby reveals the hazards, hardships, and uneven development more typical of the fledgling system at the time. The PATCO strike and the firing of striking controllers in 1981 is well known and part of recorded history, but how FAA attempts to fix the system afterward backfired, instead reproducing the conditions that caused the strike and producing NATCA, the new union, is not.

The era titles and subtitles below express the distinctive themes of each. The titles identify the dominant social actor - individual, organization, or technology - of the era; the subtitles indicate the idiosyncratic themes that typified each era. Once the airplane was invented, all three types of actors impact the system in every era, but one of the three stands out as the most definitive in each. Although the airplane was a crucial actant across eras, the emergence, development, and operation of the air traffic control system was a product of agency: structures and processes were formed and reformed by problem solving individual and organizational actors.

The Age of Innovators: 1880-1920

The Diffusion of Ideas, Networks, and Infrastructure Formation

The Age of Organizations: 1920-1950
Controllers, Technologies, and Boundary Work, Ground and Sky

The Jet Age: 1950-1980
Congestion, Technological Lag, and PATCO

The Age of Automation: 1980-2000
The Strike, NATCA, and Technological Glitches

Dead Reckoning at the Turn of the Century: 2000-2001
History, Boundaries, and Turf Wars in the Sky

Across eras, we can follow the two kinds of system effects. During system emergence (the first two eras), we see the first: how aeronaut innovators took actions, creating networks that led to aviation infrastructure formation, then how various external conditions and social actors had effects that shaped and reshaped the infrastructure, formalizing then institutionalizing it as a system of interdependent connected parts. Then, the three subsequent eras expose the second: how external conditions and social actors continue to affect the system, changing it, and in turn, impacting air traffic controllers, their work, and their actions and reactions in response.

Note that pinpointing an exact moment when a sequence of events shades into a turning point is difficult because transitions are gradual. Further, development is uneven, and events can overlap in time or occur simultaneously, be sudden and dramatic or require repetition before having an effect. These eras were "event-full," taking the form that Abbott identified for the life course of organizations: sequences of many events – "trajectories" – and those events were not equally weighted, but were of greater or lesser import/impact on the system structure, processes, and controllers.[14] Indeed, this history was marked by many turning points, the invention of the airplane being essential and major, but the airplane alone did not define the differences between eras. Instead, some turning points were internal to the eras and the turning point marking the transition to a new era seemed to be the culmination of a series of events - the trajectory as a whole, rather than a singular event.[15] So, following Abbott, it went "trajectory – turning point, trajectory – turning point, trajectory – turning point…." This was an incremental transition, with development uneven and turning points were not sudden unexpected events but typically a slow process of varying duration, only visible in retrospect - the exception being September 11th. Consequently, the boundaries between eras remain rough approximations. Also, the boundary between system emergence and system effects is blurred.

At the same time as the chapter reveals the variations *within* eras, it reveals five major substantive patterns *across* eras. These patterns overlap and move concurrently.

System Emergence, Institutionalization, and Elaboration. The system beginnings were in smaller forms of organizations – networks of aeronauts, small groups, professional associations, and early entrepreneurial business organizations - that were foundational to infrastructure formation. Legitimacy and competition were interrelated in the early development of aeroplane technology and system emergence; both legitimacy and competition remained as drivers of technological and organizational advances through the eras.[16] Early on, users initiated a specialized language, some adapted from use in other modes of transportation (highway/airway), the rest innovated to match novel system characteristics. Two crucial developments were the intervention of heterogeneous organizational actors and the emergence of a supportive organizational field, including education institutions for aeronauts that would supply the system with future engineers, scientists, pilots and research.[17] These developments were essential precedents to a system of interrelated parts.

Across eras, problem solving by heterogeneous actors drove system growth and elaboration in response to changing external conditions. During this period, the new system brought about a rearrangement of power relationships that dominated prior to its existence, as the military, the airlines, and the government formed a cooperative relationship forming a supportive organization field.[18] Once institutionalized and firmly ensconced in this supportive field, problem-solving efforts turned to refining system operation. Primary among these were increasing structural specialization and complexity and novel technologies of coordination and control uniquely crafted to suit this new form of transportation. Standardized procedures and new organizational structures were introduced to build safety and coordination across the system parts: a regulatory apparatus and training centers for air traffic controllers. Rules and procedures became more enveloping and finely filigreed in every operation. Classification categories for aircraft and boundary construction became key technologies of coordination and control.[19] Classification categories were inviolable; however, boundaries could be permeable or shut, could be expanded or contracted, such that the system could be tightly coupled or loosely coupled, as necessary.[20] In combination, these technologies of coordination and control constituted a set of strategic repertoires that incrementally lent the system resilience, reliability, and redundancy that became a durable survival strategy, contributing to institutional persistence in the face of changing circumstances and key to system safety and error reduction.

Historical Contingency. It was not a peaceful evolution. System development was uneven, shaped as much by contingent historic events and actions as by the unanticipated consequences of planned changes. Contingency came in the form of spectacular historic flights, air catastrophes, economic fluctuations, cultural shifts, changing political administrations, international competition, and war that affected resources, technology, and development in unpredicted directions. Further, time and timing mattered. Contingency came in the *co-incidence of multiple trajectories of technological innovations*, originating from independent starts in separate locations, that intersected with system development at opportune historical moments. An early example was innovators independently working on air-related technologies – ground lighting, radios, teletype – such that the separate trajectories combined to have a major effect on communication between sky and ground. Individual careers and biographies were equally important. Many people who were minor or invisible in the historic record advanced system development. As important as Charles Lindbergh's iconic oceanic flight were the feats of the many unknown aeronauts who preceded him. They carried the mail and competed in air races, giving air flight legitimacy as a service and a competitive sport, spurring the development of better and faster engines.

But even planned changes to improve the system often had unanticipated consequences. Solving one problem tended to produce another. Across eras, the creation of standards and their implementation led to resistance.[21] The introduction of a new technology was complicated by design problems that surfaced during implementation and use. As technologies grew more complex, so were the system effects. The advent of radar, computer and automation called for a technical infrastructure to mesh with the existing organization structure, creating tension between the need for standards and the need to customize according to local needs.[22] Too often the immediate effect was what Stinchcombe called "the liabilities of technological innovation:" design problems created technological lag and added unpredicted costs into the system, initially complicating controllers' ability to do their work rather than making it more efficient and safe.[23]

The Changing Nature of Work. Both material practices and the production of scientific and technical knowledge were transformed across eras. Beginning with the earliest days of fascination with flight, innovating aeronauts worked alone, initially learning from libraries, book and magazines.[24] The Wright brothers epitomized this style, developing their own specialized experimental materials and tests, cobbling together devices, and keeping systematic records. When ideas were exchanged with particular others, it was through correspondence, network ties, and small conferences. Subsequently, however, the primary sites of knowledge production shifted to organizations. The military, the government, and education institutions became the key actors not only in producing scientific and technical knowledge but also producing the products of science and technology that fed the developing airline industry. The four of them constituted the supportive organization field that drove both the development of the airplane and the air traffic control system.

From the moment in The Age of Organizations when the job of air traffic controller was created, this narrative history exposes how the social and technical combined in the system effects on the work of air traffic controllers. As aircraft equipment became capable of flying higher and higher, we witness the internal progression of architectural arrangements, technologies, and material practices that shaped their daily routine. The progression follows the earliest controllers' position on the airfield in all weather, using flags and notebooks, then their move into towers, assisted by innovations in the radio. Then, as the structure of the system became more specialized to deal with changing aircraft capabilities, controllers moved into Centers and TRACONS, aided by additional technologies that were representations of moving aircraft they could no longer see. At this point, controllers' interpretative work and thus dead reckoning dramatically changed. Devices of representation proliferated. Controllers had to acquire new cognitive skills and material practices to cope with interpretive flexibility, inaccuracy, and the liabilities of technological innovation now associated with dead reckoning. Accompanying this transformation was a status shift from airport worker, to occupation, to profession.

Precedent and Innovation. Although the first era is designated "The Age of Innovators," social and technological innovation characterized the system across eras. Often a successful innovation in one era became a precedent that carried over into the next in an elaborated form. Many innovations began as informal solutions to a local problem, then became formal, and then were institutionalized throughout the system. Those innovations that survived became more sophisticated and their use expanded to cover new situations. The pattern of informal – precedent - formal not only was essential to system emergence but a key to persistence and capacity to survive change.

The airplane, the aviation infrastructure, then the air traffic control system were all innovations that reflected the importance of precedent for innovations across eras. The Wright brothers built upon and altered the work of earlier aeronauts, both in the design of their aeroplane and their testing equipment. The first air traffic controller was a local airport operator's innovation in response to the airplane's capacity to fly high enough to need some guidance from the ground. The first spacing patterns, putting planes in sequence to keep them separated as they approached urban airports, were independently initiated by still other airport operators concerned about local problems of planes colliding. And at the turn of the century, airline quota systems at airports, instituted to make air traffic manageable for a drastically reduced controller staff in the aftermath of the 1981 PATCO controller firings, were again invoked as a strategy for maintaining surveillance when controllers began getting airplanes back in the sky in the aftermath of September 11th.

The Sky as a Socio-Technical System. An innovation with no apparent precedent was the social structuring of the air. The sky as nature was transformed into an artificial construct, a virtual space.[25] As air transportation increased, first the government, then the fledgling air traffic control system, responded to catastrophic air collisions by creating boundaries in the sky that classified airplane equipment into categories with similar capabilities to keep them separated. Struggling to create order out of disorder as the airplane developed more sophisticated capabilities and air traffic changed, government actors made boundaries more refined, sorting airplanes by altitude and direction. A precedent was set such that creating, moving, and reorganizing boundaries in the sky became institutionalized as a key technology of coordination and control. The corollary development was that structures on the ground incrementally were constructed to hold the people and devices that enabled communication with pilots: first small structures, or "stations," then towers, then centers. As boundaries in the sky became more specialized and refined, so did division of labor between and within the structures on the ground.

The standardization of the sky made it a site of contestation. Across eras was a continuing dynamic about where the locus of control of the sky should be: in the sky or on the ground. Gras et al. brilliantly pose it as an ongoing power struggle between the "Icarus model," where the control is in the device in the sky, and the "mechanical bird model," where control is in devices on the ground.[26] This history shows the moments when the locus of dead reckoning first shifted from the pilot, flying in the sky and in nature (Icarus), to the air traffic controller on the ground using communication devices, then the transition to technologies of representation (mechanical bird). Across eras, dead reckoning has three turning points that mark this incremental shift. Each turning point was contested. Recurring across history, this conflict about the locus of control was re-enacted in disputes about safety strategies in response to an accident, arguments for and against automation versus devices in the cockpit, and in late 20th century proposals for a return to "free flight" for pilots, this time aided by Global Positioning Systems, versus proposals that would replace air traffic controllers with automation. Moreover, the contest for control of the sky manifested *between* the controllers working in the structures on the ground. The boundaries in the sky had social and symbolic meaning: divisions of airspace had become both territory owned by and conferring status upon controllers in the facilities that worked it.[27] Competition between facilities ensued to retain, increase, or keep their airspace territory - and hence, status and salary - from shrinking.

These five patterns are visible within and across eras, affecting controllers, their knowledge production process, their work practices and their experiences into (what was in 2000) the unfolding present.

<u>Conclusion</u>

This section will be written between now and July. In it, I will address the subject matter in the last sentence of the abstract:

The conclusion addresses how this case both conforms to and deviates from the typical event history analysis in historical sociology, the difference and similarities in the patterns found, and how analyzing formation stories as causal accounts can build the analytic and theoretical repertoires of historical sociology, history of technology, and organization theory and how the three compliment each other.

Also, I hope to have a power point of a timeline that gives an overview of events, major and minor, that describe the growing complexity and shifting of the system structure and boundaries and technologies over the life course of the system and history emergence and transformation. I have not tried this yet, and I hope it is doable. I want it to be true to contingency but causal, so cannot create a timeline that looks to be strictly linear, path dependent model. Not sure this will work until I try.

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[1] William H. Sewell, Jr. (1991) 1996. "Three Temporalities" in T. J. McDonald, ed., *The Historic Turn in the Human Sciences*. Ann Arbor: University of Michigan Press. 245-80; William H. Sewell, Jr. 1992. " A Theory of Structure: Duality, Agency, and Transformation." *American Journal of Sociology*: 1-29. Jeffrey Haydu. 1998. "Making Use of the Past: Time Periods as Cases to Compare and as Sequences of Problem Solving." *American Journal of Sociology* 104, 2: 339.71.

[2] Ron Aminzade 1992."Historical Sociology and Time." *Sociological Methods and Research* 20: 456-80; Andrew Abbott, 1992. "From Causes to Events," *Sociological Methods and Research* 20: 428-55.

[3] Larry J. Griffin 1992. "Temporality, Events, and Explanation in Historical Sociology: An Introduction." *Sociological Methods and Research*. 20: 413-14.

[4] In constructing this history, I wanted to find an ordering of events that was inherent in the chronology of archival data, independent and uninfluenced by what other scholars thought or did in constructing historical accounts. Working inductively, I created the narrative history and analysis based on my previous research experience with historical chronologies (Vaughan 1986; 1996) and from the latter, my knowledge of organization theory and science and technology studies. I followed the rhythm that events themselves seemed to dictate. Making boundaries in a continuing historical process is admittedly artificial and arbitrary. However, it is essential to understanding origin, change, persistence, or demise in the life cycle of any organizational form, small or large, over time. As in my previous research, I could identify turning points: a trajectory of events that either seemed to change the direction of or add a new dimension to the characteristics, activity, and life cycle of the organizational form I was studying. I tentatively marked boundaries, and as I learned more of system history, adjusted them until they accounted for the full trajectory of events that led to a turning point so major that it seemed to mark the end of an era in the life cycle and the beginning of a different

one. As I read more history, I reworked boundaries until eventually new discoveries did not alter them, but fit into them. Only when I arrived at the five stable era boundaries presented here, did I turn to historical sociology and history of technology to find out the extent to which this chronology either fit or deviated from what was known in those areas of specialization. Being in a department with Chuck Tilly and knowing a little about Thomas Hughes' work, I was only vaguely familiar with how these two areas might be relevant to this particular case.

[5] Jeffrey Haydu, 1998. "Making Use of the Past."

[6] William H. Sewell, Jr. 2005. *Logics of History: Social Theory and Social Transformation*. Chicago: University of Chicago Press: 100.

[7] Daniel Hirschman and Isaac Ariail Reed, "Formation Stories and Causality in Sociology," *Sociological Theory* 32,4 (2014): 259-282.

[8] Daniel Hirschman and Isaac Ariail Reed, 2014: 260. "Formation Stories."

[9] Trevor J. Pinch and Wiebe Bijker, "The Social Construction of Facts and Artefacts: Or how the Sociology of Science and Technology Might Benefit Each Other." *Social Studies of Science* 14 (1984): 399-441; Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, (eds.) *The Social Construction of Technical Systems*. 1987; Donald MacKenzie and Judy Wajcman (eds), *The Social Shaping of Technology* (Milton Keynes, Bucks and Philadelphia: Open University Press, 1985).

[10] Hughes, *Networks of Power: Electrification in Western Society* (Baltimore MD: Johns Hopkins University Press, 1983); Hughes, *American Genesis: A Century of Invention and Technological Enthusiasm, 1870-1970*. (Chicago: University of Chicago Press,1989).

[11] Thomas P. Hughes. "The Electrification of America: The System Builders," *Technology and Culture* 20, 1 (1979):124-61; Michel Callon, "Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay," *The Sociological Review* 32, S1 (1984): 196-233; John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Explansion," in Bijker, Hughes, and Pinch (eds) 1987. *Social Construction of Technical Systems*; Bruno Latour*, Reassembling the Social: An Introduction to Actor-Network Theory* (Oxford, UK: Oxford University Press, 2005).

[12] Jeffrey Haydu, 1998. "Making Use of the Past."

[13] Andrew Abbott, "Transcending General Linear Reality," *Sociological Theory* 6, 2 1988: 173; Michel Callon and Bruno Latour, " "Unscrewing the Big Leviathan; or How Actors Macrostructure Reality and How Sociologists Help Them to do So," in *Advances in Social Theory and Methodology* (eds.) Aaron Cicourel and Karin Knorr. (London: Routlege/Kegan Paul, 1981).

[14] Andrew Abbott, "Conceptions of Time and Events in Social Science Methods," Chapter 5 in Andrew Abbott, *Time Matters: On Theory and Method*. Chicago: University of Chicago Press, 2001: 181. Abbott refers to this as a "career model" for which he is thinking about individual careers, but organizations also have "careers." So it makes sense that the patterns, discontinuous or not, would be analogical. See Abbott's reference to life course and organizations, p. 182

[15] See Abbott on sub-sequences within sequences and turning points. Andrew Abbott, "On the Concept of Turning Point," Chapter 8 in Andrew Abbott, *Time Matters*: 250.

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[16] See Paul J. DiMaggio and Walter W. Powell. 1983. "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields," *American Sociological Review* 48,2: 147-160. Although DiMaggio and Powell seem to set aside competition and instead stress legitimacy in the beginning of this iconic article, here I found them operating together.

[17] Paul J. DiMaggio and Walter W. Powell. 1983. "The Iron Cage Revisited."

[18] For a discussion of this structural transformation, see Elizabeth S. Clemens. 2007. "Toward a Historicized Sociology: Theorizing Events, Processes, and Emergence." *Annual Review of Sociology* 33: 527-49.

[19] Timmermans, Gieryn, Bowker and Star

[20] Abbott, "Things of Boundaries."

[21] Timmermans and Epstein, 2010.

[22] Susan Leigh Star and Karen Ruhleder. 1996. "Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces." Information Systems Research. 7, 1: Information Technology and Organizational Transformation: 111:34. Timmermans and Epstein, 2010.

[23] Arthur L Stinchcombe 1965. "Social Structure and Organizations," in James G. March, ed. *Handbook of Organizations*: 142-93.

[24] Hughes article or Genesis?

[25] Alain Gras, Caroline Moricot, Sophie L. Poirot-Delpech, and Victor Scardigli, trans. Jill Lundsten, 1994. *Faced With Automation: The Pilot, the Controller, and the Engineer.* Paris: Publications de la Sorbonne. Condensed version of *Face a L'Automate: Le Pilote, le Controleur et L'Ingenieur.* 1991. Paris: Publications de la Sorbonne.

[26] Gras et al.

[27] Michele Lamont and Virag Molnar 2002. "The Study of Boundaries in the Social Sciences." Annual Review of Sociology: 167-95.