Studying the Co-evolution of Individual Actions and Emergent Social Structures using Digital Trace Data

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Short Paper

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Abstract

The information systems field has a long-standing interest in how individual actions co-evolve with social structures. Yet, studying the exact process of co-evolution turned out to be elusive. We propose a novel way to study this co-evolution using digital trace data. By analyzing the sequences of individual actions through digital trace data and the process of emergent social structuring expressed in collective action patterns, we can measure the recursive influence of individual actions and the process of emergent social structuring over time. We illustrate our approach using data from GitHub. We analyze the social structuring expressed through collective action patterns of a project and compare them with the idiosyncratic action patterns of individual developers. Our research has implications for studies that examine the connection between social structures and individual actions. Our approach particularly allows us to investigate the role of power and social influence in structuration processes.

Keywords: Action patterns, GitHub, social influence, rockstars, digital traces, routine dynamics

Introduction

Scholars in the information systems field have repeatedly shown that actions by individual actors shape and are shaped by emergent social structures (Barley 1986; Leonardi 2013; Orlikowski and Scott 2008). Whether it is in the context of open-source communities, large-scale enterprise systems implementations, or the use of social media platforms, individual actions and social structures are intercalated, mutually and reciprocally shaping each other. Traditionally, scholars have applied qualitative research approaches, such as interviews and ethnographies to study the recursive influence between these two (Essén and Värlander 2019; Faik et al. 2020; Leonardi 2013; Orlikowski 2007). Precisely measuring and pinpointing the extent

to which individual actions are involved in the shaping of emergent social structures – referred to as the process of emergent social structuring – has not been feasible yet.

In this research in progress, we draw from a recent approach by Pentland et al. (2022) and propose a novel approach to connect the *realm of action* with the *realm of structure* leveraging digital trace data (Essén and Värlander 2019). In a nutshell, we suggest that by analyzing digital trace data at the individual and collective levels simultaneously, we are able to understand how individual actions and emergent social structuring co-evolve as individuals perform specific tasks, which in turn, form emergent social structures through patterning (Pentland et al. 2022). Thereby, through analyzing performing and patterning of sequences of actions through digital traces, we can gain a more dynamic and detailed view of the recursive and mutually constitutive relationship between emergent social structuring and individual actions. When we observe collaborative virtual work, for example, we can consider an actor's typical habits and preferred action sequences that have been espoused in other projects (Grisold et al. 2021). Such information can help us explain the influence that an actor has on the emergent social structure of a focal project and vice versa. Furthermore, we can also examine how an influential individual can affect other individuals' actions working on the same project.

We showcase our approach by drawing from GitHub, the largest collaborative software development platform (Zöller et al. 2020). We analyze a large project on GitHub and assess the emergent social structuring in the form of stable patterns of actions that form and are enacted in the project over time (Lindberg et al. 2016). At the same time, we trace the actions of individual developers across other unrelated projects, which we refer to as exogenous projects. By assessing the idiosyncratic action patterns of an individual actor across multiple projects, we then compute the extent to which the developer influences the emergent patterns of actions at the project level. Furthermore, this allows us to precisely compare the extent to which different developers influence the emergent structure of the project and other developers' actions on the project. Our work has implications for studies that are concerned with the recursive influence of individual actions and emergent social structures (Essén and Värlander 2019; Faik et al. 2020; Orlikowski 2007).

Theoretical Background

Co-Evolution of Individual Actions and Emergent Social Structuring Through Performing and Patterning

It is an age-old question that has been addressed in sociology, information systems research, organization studies and management science: To what extent do individuals influence emergent social structures, and vice versa? (Felin et al. 2015) How do the different attributes and social positions of actors influence the degree to which they shape emergent social structures? In the information systems field, this question has been approached from different angles (Essén and Värlander 2019). These include critical realism (Volkoff and Strong 2013), structuration theory (Giddens 1984), institutional logics (Faik et al. 2020), complexity theory (Benbya et al. 2020) and socio-materiality (Orlikowski 2007). All of these perspectives shed light on the influence of individual actions—including interpretations, decisions and actions—on social structures, such as routines or shared understandings. The key idea here is that individual actions lead to social structures, and social structures influence individual actions (Faik et al. 2020).

Drawing from this stream of research, we see that social structures emerge through a recursive and reciprocal interactive process between individual actions and social structures. We refer to this as *emergent social structuring*, a process by which individual level actions recursively and reciprocally co-evolve with social structures that are expressed through larger collective patterns of actions. The process of emergent social structuring is characterized by a duality of stability and change (Farjoun et al. 2015) as social structures are stable and recognizable, while always remain malleable and generative at any specific points in time. This recursive and reciprocal co-evolutionary process of emergent social structures and individual actions happens through performing and patterning (Pentland et al. 2022). Performing refers to the specific actions taken by developers at specific points in time; patterning refers to patterns of actions that indicate how organizing is accomplished in a given context (Goh and Pentland 2019). Figure 1 illustrates the duality of emergent social structuring.

Figure 1. The Recursive Influence between Individual Actions and Emergent Social Structuring
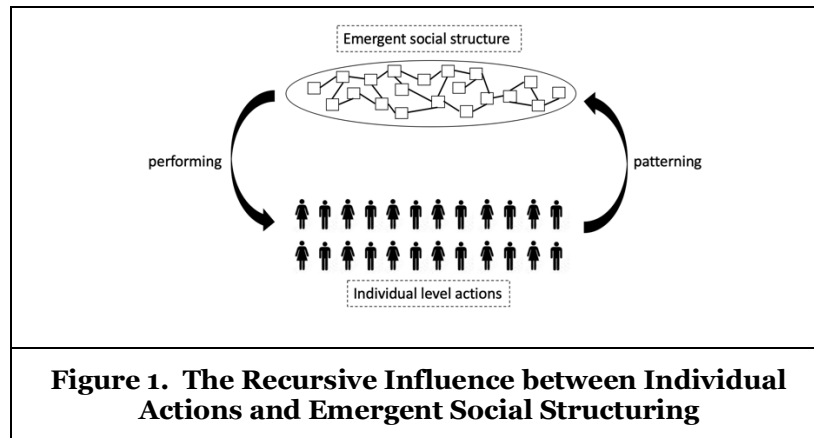
The large share of studies in the information systems field has been paying particular attention to the role of technology, and how individuals' enactments of a specific technology lead to social structures and institutionalized patterns of practices (Barley 1986; Faik et al. 2020). Across these studies, we find different explanations about why and how individual actions recursively shape and are shaped by emergent social structuring. In a recent study, for example, Essen and Varlander (2019) report on three practices that translate individual actions into emergent social structures; individual local actors (1) shape the material features of specific technology such that it aligns with social structures, (2) find new action opportunities through improvising with technology, and (3) engage in verbal framing to align individual actions and social structures.

From the extant literature, we can make three key observations. First, individual actions shape emergent social structuring when they align and play together. Social structures are more than the sum of individual activities (Felin et al. 2015). Social structures emerge when individual actions lead to patterns of "interlocked behavior" (Dionysiou and Tsoukas 2013); they take form when individuals engage in shared understandings, beliefs, roles and/or routines (Essén and Värlander 2019; Faik et al. 2020; Leonardi 2013). Second, individual actions have a high variability, that is, the ways in which they are enacted change. This variability can be observed across individual actors (Barley 1990; Barrett et al. 2013; Orlikowski 2000), for instance, as they have different roles (Davidson and Chismar 2007), institutional logics (Seidel and Berente 2013), cultural backgrounds (Su 2015), or operate on different organizational sites (Leonardi 2013). Third, individual actions and emergent social structuring co-evolve *over time*; change occurs, for example, when individual actions gradually influence social structures, such as institutional logics (Essén and Värlander 2019), organizational routines (Pentland and Feldman 2007), or are influenced by outside factors, such as pressures from the side of the government (Orlikowski 1992). Despite the growing theoretical insights on the co-evolutionary and mutual reciprocal constitutive relationships between individual actions and emergent social structuring, we still lack ways to formalize and measure these recursive influences.

Studying Actions with Digital Trace Data

We build on the emerging interest to use digital trace data in order to analyze the performance of actions, and how they lead to patterns of actions over time (Gaskin et al. 2014; Pentland et al. 2017a; Pentland et al. 2022). Digital trace data enable us to see what happens as socio-technical phenomena evolve and take shape. They represent digital footprints that are left behind when actors perform actions with digital technologies (Pentland et al. 2021). Since digital technologies penetrate almost every aspect of our organizational and private lives (Baskerville et al. 2019), they are abundant in all kinds of contexts. Digital trace data typically appear in large quantities and entail information about actions on granular levels.

For this study, we want to highlight two key advantages of using digital trace data to study the relationship between individual actions and emergent social structuring. First, digital trace data are usually collected at the individual level but can be used to identify emergent collective patterns of actions. Google search trends, social media screening or mobility patterns are aggregations of countless individual actions. Consider, for example, recent studies focusing on the spread of Covid-19 (Oliver et al. 2020). These studies have been

using digital traces from individual mobile phone use to compute large-scale mobility patterns at the population level. Digital trace data enable us to find patterns by *zooming out* of individual actions, while they also allow us to attend to idiosyncratic individual actions by *zooming in*.

Second, digital traces have been considered particularly useful to study change and evolution over time (Berente et al. 2019; Tremblay et al. 2021). Digital trace data are typically equipped with temporal information that depicts when a certain action was performed (Pentland et al. 2020b). Hence, digital trace data can be used to reconstruct the temporal dynamics of a given phenomenon and explain it in terms of its temporal unfolding (Lazer et al. 2020). For our study, digital traces help us to follow the change in individual actions and emergent social structuring, allowing us to study their recursive interactions and co-evolution.

Connecting Individual Actions and Emergent Social Structuring: An Empirical Showcase

We showcase our idea by drawing from GitHub. GitHub is the largest open-source software development platform with more than 40 million registered users. The platform offers developers different features to build, ship, and maintain software projects. Actions that are taken by developers on the platform throughout a specific project are stored in event logs. Even logs contain specific information about every recorded action: which type of action was taken, who took it, and when it was taken. These event logs can be retrieved through an application programming interface provided by GitHub.

GitHub is particularly suitable for the purpose of our argument. GitHub offers a fixed set of 16 different action types (in GitHub, they are called "event types") that represent different forms of actions (including, for example, the "push event" that allows developers to push new data to a project, or the "issue comment event" that enables developers to comment on an issue that arises within a project). This fixed set of event types allows us to examine and directly compare structures of GitHub projects as well as individual level action of developers. Using these 16 event types, we can analyze actions both at the project and individual levels. Projects are typically composed of a large number of developers (sometimes as large as thousands) who work on a given project together. Previous research has shown that projects exhibit social structures that emerge through a complex interplay of individual level actions; these structures are represented through patterns of actions (Grisold et al. 2021; Lindberg et al. 2016). At the same time, we can thoroughly analyze each individual developer's actions across multiple projects that the developer is working on. We can thus examine how an individual developer typically behaves across multiple projects as well as in a specific project. Thus, we can see what types of actions are involved in emergent social structuring in a given project, while we can also see what types of actions were taken by specific developers.

In what follows, we showcase our argument. We (1) analyze one large project on GitHub and specify the building blocks that represent emerging structuring in the project; (2) examine individual developers as they perform their task, enacting emergent stable patterns of actions of the project, (3) show how one specific actor behaves across multiple exogenous projects, and (4) depict how this developer influence the emergent structuring of the project over time.

Step 1: Assessing the Emergent Social Structuring in a Project

We draw from a large GitHub project: "avajs/ava", a test framework for JavaScript applications. The project started in May 2016 and has been further developed ever since. In sum, 3,790 developers have been contributing to this project. Over the past years, a total number of 63,088 actions have been recorded, which we retrieved and analyzed. The number of events and the number of actors allows for a thorough analysis of the process of emergent social structuring in the selected project. Figure 2 shows the distribution of all actions over time.
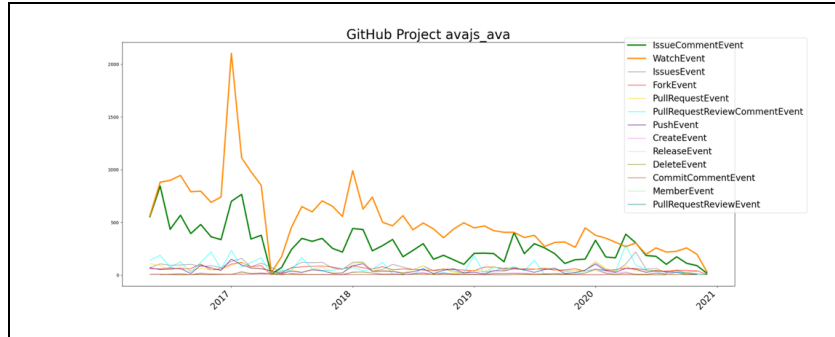
Figure 2. Action Distribution of the Selected GitHub Project

In the next step, we analyze the social structuring in the project, as represented through emergent patterns of actions that are enacted through all developers who perform their own tasks for the project (Grisold et al. 2021; Pentland et al. 2020a; Pentland et al. 2017b). We do so by computing the probability of sequences of action pairs. The exhaustive list of all possible action pairs—two consecutive actions that occur one after another—with the transition probability between the actions represent basic building blocks of social structures of the project. Recurrent sequences of action pairs represent dominant patterns of actions in a project (Pentland et al. 2020a; Pentland et al. 2022). When two actions repeatedly occur one after the other, it means that the sequence of these two actions is an important building block of the emergent social structuring in this project as developers are performing tasks. Because every project is unique with respect to its goal, required tasks, and the developers who are involved, the probabilities of sequences of action pairs are idiosyncratic to a given project.

We calculate the probability on the grounds of the total frequencies of sequential action pairs, as compared to all actions that have taken place. The visual representation of the action pair matrix and how it changes over time is shown in Figure 3. It illustrates the matrices from two points in time (2016 and 2020) as heat maps (Mahringer 2021). Action pairs with a high probability (indicated e.g. in red) have been occurring sequentially in the past and thus have high probability to occur again in the future (Pentland et al. 2022). Actions pairs with a low probability (e.g. light blue) have rarely been seen to occur together in the past, and they have a low probability to occur in the future. We see that the probability changes over time, which indicates temporal unfolding of the process of emergent social structuring.
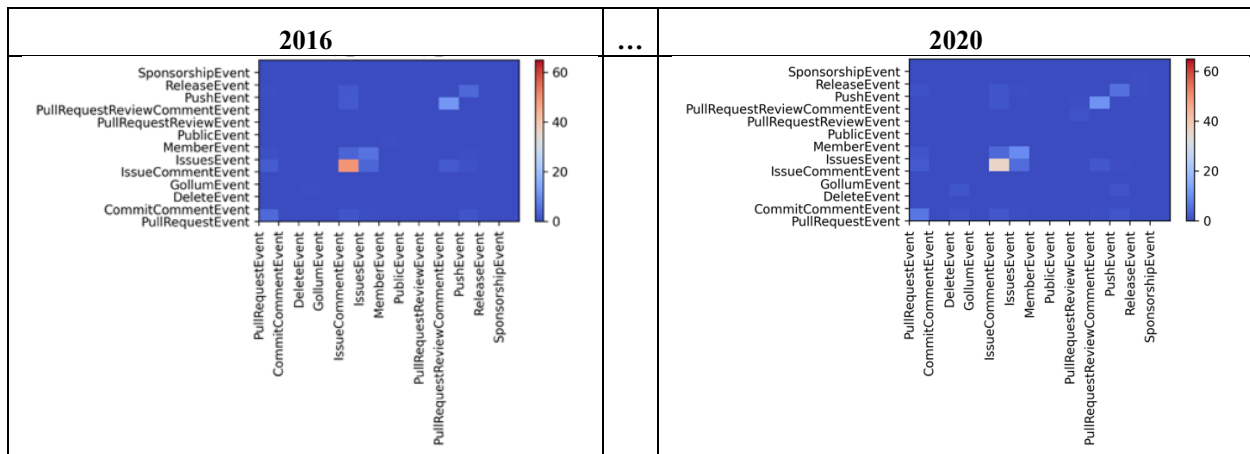

Figure 3. Matrices Depicting the Probability of Sequential Action Pairs in the GitHub Project avajs/ava Over Time.

Step 2: Analyzing Individual Level Actions of Developers

In the next step, we focus on the developers' individual actions who perform tasks in the project "avajs/ava". For this purpose, we selected different developers who are involved in the project. Figure 4 shows the probability of sequential action pairs as depicted by the project owner and three other developers who contribute to this project. Upon visual inspection, we can see that the sequential action pair matrices differ across developers, showing distinct individual patterns, while at the same time preserving a certain degree of similarities with the action pair matrix of the project.

To provide a more systematic exploration of the relation between individual developers and the larger structure of the project, we calculated the similarities of the sequential action pair matrices between each developer and the project using the Euclidean distance (Danielsson 1980). The Euclidean distance is a well-recognized approach to study similarities of matrices in organizing contexts (e.g. Pentland et al. 2012). The computed Euclidean distances are shown under the action matrices. These show that the project owner is closely aligned with the overall project structure. The same holds for developer 3 who is very active on GitHub and enjoys a high reputation among other developers (such renowned developers are typically referred to as 'rockstars', see Zöller et al. 2020). The action pair matrices of developers 2 and 3, in contrast, have high Euclidean distances to the overall project structure.

Taken together, the analysis of individual actions of developers indicates that some developers (project owner and developer 3) are more involved in the emergent social structuring in the project, as represented through the probability of sequential action pairs. Other developers (developers 2 and 3) are less involved in emergent social structuring.
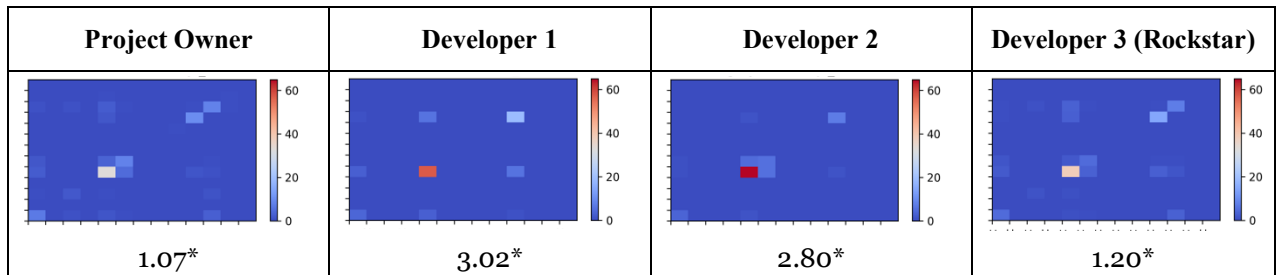
Project Owner	Developer 1	Developer 2	Developer 3 (Rockstar)
1.07*	3.02*	2.80*	1.20*

Figure 4. Matrices Depicting the Probability of Sequential Action Pairs of Individual Developers in the Selected GitHub Project

*Euclidean distance calculated on the action pair matrices compared to the project DNA.

Step 3: Analyzing Performing of Individual Actions of a Developer Across Exogeneous Projects

We can also analyze individual developers perform actions across exogenous projects. Hence, we can see how their actions in exogenous projects and their actions in the focal projects interact, and how emergent social structures of a project can influence individual actions beyond the boundary of the focal project. Figure 5 shows the sequential action pair matrices of developer 3 (see Figure 5), and how he/she behaves across exogenous projects that are not related to the project "avajs/ava" (see Step 1 and Step 2).

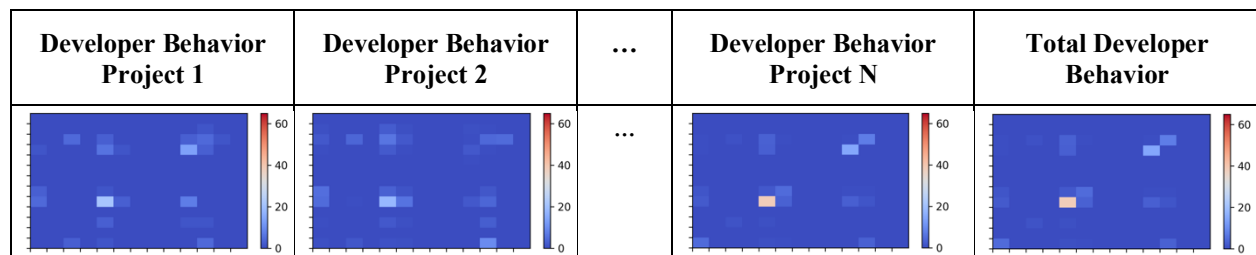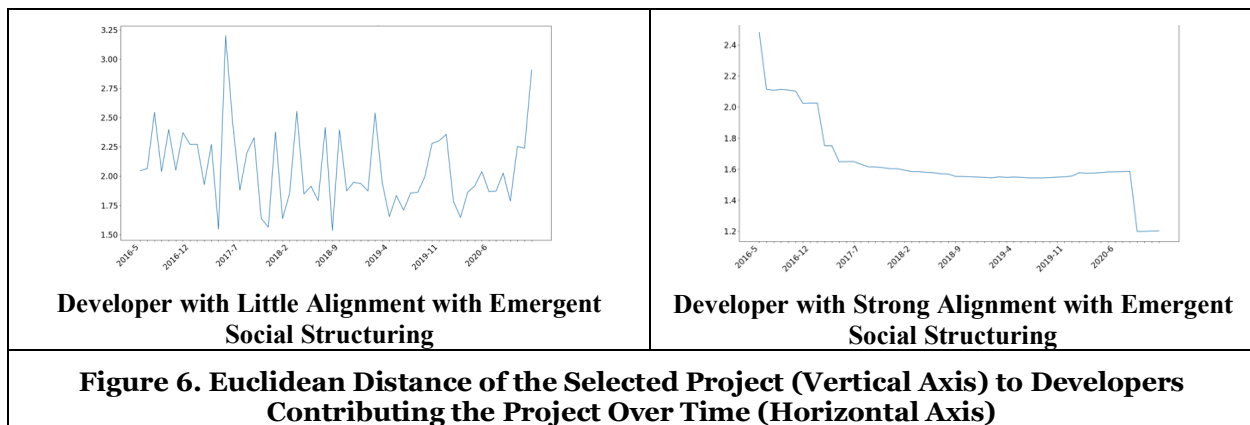| Developer Behavior Project 1	Developer Behavior Project 2	…	Developer Behavior Project N	Total Developer Behavior
		…		

Figure 5. Sequential Action Pairs of Developer 3 Across Exogenous Projects

We see that the developer behaves differently from project to project, although the differences vary depending on the project (e.g., high with Projects 1 and N, while low with Projects 1 and 2). Furthermore, we can see that overall patterns of action of developer across all projects (Total Developer Behavior) align more or less with single projects. This, in turn, allows us to see the extent to which the developer's actions and the emergent structuring of the project recursively and reciprocally interact with one another.

Step 4: Temporal Analysis of Individual Actions and Project Structure

Finally, we shed light on the co-evolutionary pattern of individual actions and emergent social structuring of the project. Figure 6 depicts the Euclidean distances between the individual level actions and emergent structuring over time. We see that developers can have a lower alignment with emergent social structuring (left), or a higher alignment (right).

Developer with Little Alignment with Emergent Social Structuring	Developer with Strong Alignment with Emergent Social Structuring

Figure 6. Euclidean Distance of the Selected Project (Vertical Axis) to Developers Contributing the Project Over Time (Horizontal Axis)

Expected Contributions

Our research is expected to provide several implications that center around the question of how individual actions and emergent social structuring reciprocally and mutually constitute each other and co-evolve over time.

First, we contribute to studies that trace the recursive influence between individual actions and the formation of larger structures over time (Essén and Värlander 2019). Recent arguments indicate that such a perspective is important to understand why, how and when socio-technical phenomena take shape. Mousavi Baygi et al. (2021), for example, traced the evolution of Twitter as a political campaigning tool during the US tea party movement. They suggest that this process can be best understood as "flowing lines of action" (p. 423) that emerge, co-evolve and merge over time; as individual actors perceived and enacted emerging action opportunities, they contributed to the formation of larger action patterns that worked in favor of the political campaign. The approach we present here allows us to investigate this process in more detail. Drawing from digital traces from Twitter both on the level of individual actions as well as the emergent social structuring of the campaign, we can precisely answer such as: *When and how were actions by individual users translated into larger action patterns? How did other actors influence and form larger action patterns? How did the formed structures influence the behavior of individual users?*

Second, our approach allows us to paint a more nuanced picture of co-evolutionary processes between individual actions and emergent social structuring. To this end, we can understand, for example, how and to what extent such processes are influenced by power and social influence (Grisold et al. 2021; Huang and Chung 2019). Typically, it is implicitly assumed that there is an even balance between individual actions and larger structures – the focus is on how one influences the other (see Figure 1). Research on organizational routines (Feldman et al. 2021) is a case in point. Here, research is interested in processes where the actions of individuals create and recreate the social structure of the routine that is shared among actors (Dionysiou and Tsoukas 2013). While recent research indicates that some individuals exert more influence on the patterning of the routine than others (Kremser and Blagoev 2021), we know next to nothing about the role of power in structuration processes. Our approach can extend such works by investigating and formalizing the role of power that certain individuals exert.

Acknowledgments

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