Social and physical coordination

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The English word "coordination" exhibits a suggestive ambiguity. On the one hand, coordination refers to the way that the different elements of a complex body are organized so that they work together efficiently. This is the familiar sense of eye-hand coordination, for example, or the type of coordination exhibited while walking or carrying on any complex physical activity. On the other hand, we often speak of social coordination, the ability of individuals to bring their social activity into harmony, where each individual makes an appropriate and timely contribution to some joint task.

The study of motor coordination by physiologists and psychologists has demonstrated that there is a general sense in which joints are analogous to a number of autonomous agents solving an optimization problem; there is no central controller dictating each elements actions. Equally, when we enter into a situation where we must coordinate our behavior socially, there is often no need for a central control to determine our individual choices. Can the techniques for solving one kind of optimization problem, physical movement, be viewed as analogous to optimizing one's preferences in a social decision task?

As I will endeavor to show in Section 2 there does seem to be a smooth transition from motor coordination in one individual to motor coordination across individuals (see, for example, Turvey (1990) for an overview).[1] Physical coordination, in fact, seems to play a role in how we coordinate our social selves; gesture and eye-gaze, for example, play crucial roles in shaping mental representations and communicating the contents of those representations. If this is correct, then our understanding of social coordination can be deeply enriched by studying physical coordination; one might argue, in fact, that language and social coordination evolved out of physical coordination and, thus, obeys many of the same laws. Thus, physical coordination informs how we think about mimesis and its relation to language evolution (Donald (1991)); gesture, eye-movement and motor coordination should be fundamental elements in the study of distributed language (Cowley (2007), Cowley (2009)). Studying the connections between physical coordination and social coordination should be fundamental to our understanding of the ecology of language and language use.

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In Section 1, I will turn to a general discussion of social coordination and its relation to strategic decision-making. Section 2 gives a broad discussion of the study of physical coordination in physiology and psychology and relates this study to cognition and communication. Finally, the conclusion summarizes both the similarities and differences between social and physical coordination.

1. Games and social coordination

Let's turn, first, to social coordination. The problem was clearly laid out by David *Hume in his Treatise of Human Nature* (Hume (1985)):

> Two men who pull the oars of a boat, do it by an agreement or convention, tho' they have never given promises to each other. Nor is the rule concerning the stability of possessions the less deriv'd from conventions, that it arises gradually, and acquires force by a slow progression, and by our repeated experience of the inconveniences of transgressing it... . In like manner are languages gradually established by human conventions without any promise.

We often bring our behavior into alignment in order to accomplish some mutually desirable end. In general, coordination involves decision-making by two or agents, where the outcome of the decision for any one agent depends on the decisions of the other agents; finally, the agents can agree on which outcomes are stable and desirable.

In order to illustrate this, consider the question of whether to drive on the left- or right-side of the road. Either outcome works, as long as we all agree to drive consistently on one side or the other. I've shown the problem as a game in Figure 1. One player, the row player (Driver 1), has two strategies, "Drive Left" and "Drive Right." Equally, the column player (Driver 2) can also choose one of two strategies – "Drive Left" and "Drive Right."

		Driver 2	
		Drive left	Driver right
Driver 1	Drive left	10, 10	– 10, – 10
	Drive right	– 10, – 10	10, 10

Figure 1. The driving game

The preferences of the two players are shown in the cells of the matrix in Figure 1. If both drivers drive on the left-side of the road or both drivers stay on the right-side of the road, they avoid accidents. The drivers prefer to avoid accidents, so I've given them a positive return in the cases where they coordinate their behavior. On the other hand, if one driver drives on the left and the other drives on the right then accidents become inevitable, something both drivers want to avoid. If they fail to coordinate I've accorded them a penalty, – 10 points each.

Notice that both drivers prefer to coordinate; both (Drive Left, Drive Left) and (Drive Right, Drive Right) are *equilibria*; if both drivers choose left, then no one driver has any motive to change strategies and drive right. Equally, if both have elected to drive on the right, then no one driver would want to switch and drive on the left, since the outcome would be worse for him. Self-interest dictates that drivers should coordinate their behavior; both drivers can agree on what the equilibrium points are, but they need to agree on which equilibrium point to select; this problem of equilibrium selection is a hallmark or coordination games.

Everyone has an interest in a uniform solution to the driving game and, indeed, coordinating conventions evolve to decide the question. In general, agents are left to their own devices to work out which equilibrium point to coordinate around. One equilibrium might stand out (Schelling (1960); Sugden (1995)). For example, we might want to meet up; we could choose to might either at the local coffeehouse or at the health food store; since we both prefer coffee to tofu, the choice is obvious. We both get more utility from caffeine!

I've shown the game in Figure 2. Notice that there are two equilibrium points; both (Coffeehouse, Coffeehouse) and (Health Food Store, Health Food Store) are equilibria since unilateral defection yields a worse result for the defector. Nevertheless, we both prefer meeting at the coffeehouse; (Coffeehouse, Coffeehouse) is *Pareto efficient* since no other equilibrium offers either player a higher payoff; it would seem to provide a focal point for coordination since both players, interested in the best outcome, are inclined to select it.

		You	
		Coffeehouse	Health food store
Me	Coffeehouse	5, 5	0, 0
	Health food store	0, 0	2, 2

Figure 2. Where to meet?

The players' interests do not necessarily need to coincide perfectly in a coordination game; you might prefer health food to coffee, while I need a latte. We both prefer meeting to not meeting, but in this case our preferences do not match perfectly; see Figure 3. In this case, you might send me a message that you are going to the Health Food Store. Since I have every reason to believe you – you benefit not at all by deceiving me – I should go to the health food store, although it's not my preferred outcome; because there is no advantage to either party misleading the other, the game has a *cheap talk equilibrium*, (Health Food Store, Health Food Store), unlike some other coordination games – the Prisoner's Dilemma, for example – where one player might profit by misleading the other.

		You	
		Coffeehouse	Health food store
Me	Coffeehouse	2, 1	0, 0
	Health food store	0, 0	1, 2

Figure 3. The meeting game with mismatched preference

Hume was quite right in supposing that languages are instances of coordination problems. In the case of language, one agent makes a signal and the other agent associates a content with that signal. The content of a signal is not fixed in advance.

To see this, let's suppose we're in my house. You are standing in my kitchen and I ask you, from another room:

(1) Could you bring me the thing on the table?

You look about and see the following scene:

Your problem is to select an object given my signal; which object do you take to be the content of the phrase "the thing on the table?" We coordinate if you select the object that I intended to refer to by using the phrase "the thing on the table."

There are three candidates for "thing" in the picture: the book, the toy and the tablecloth. Most people select the brightly colored toy as opposed to the book. No one selects the tablecloth. The toy is, in some sense, the most salient candidate for thinghood on the table, another example of a Pareto efficient *focal point*, analogous to the coffeehouse in the example in Figure 2. The reasoning is that if I had intended the book I would have said "book." But this account is too thin; the very oddness of the toy makes it salient and, therefore, the best candidate for the referent of "the thing on the table" – neither the book nor the tablecloth stand out – and, indeed, the toy is the object most people pick. The factors that lead to successful reference of a definite NP have been extensively studied by Herbert Clark (see the papers collected in Clark (1992)) who lays out conditions on joint knowledge; Clark (2011) discusses the role of focal points in language and concept formation and relates them to H. Clark's important contributions. Coordination games provide an interesting framework for studying the elements of reference in natural language.

The example illustrates how the environment and our relationship to the environment contributes to our ability to coordinate signals and contents. Part of our ability to coordinate our behavior – whether that behavior is linguistic or not – arises from our capacity to reflect on how other agents, essentially like us but perhaps with only partially aligned interests, will behave given a certain set of goals and plans. This ability is related no doubt to *theory of mind*, our ability to think about what others know or believe.[2]

Despite the dynamic nature of coordination problems, we should stress the role of conventions and conventionality in working out coordination problems. This point is stressed in Lewis (1969), who also notes the role of focal points in coordination. We should here note the role of social evolution in the formation of conventions (see, in particular, Young (1993) and Young (1998)). Equilibrium states can function as attractors in an evolutionary system so that over the long term they become expedient solutions to equi-librium selection in coordination games.

2. Physical coordination

Social coordination involves action whose outcome depends on the choices of one or more rational agents. By "rational" I simply mean that the agents want the best possible outcome[3] given the choices at hand and have some capacity for judging the outcomes of their choices in the context of the coordination task. At first, physical coordination, by which I mean motor coordination of a very general sort, would seem rather different. An activity like walking depends on the simultaneous action of my joints and muscles as well as feedback from a number of systems designed to maintain my balance as I walk. While my ability to walk is contingent on the interaction of my joints and muscles, it doesn't seem as though they are involved in rational decision making in any interesting sense. The relationship between social and physical coordination, however, shows some surprising parallels.

If we think of the body as an assembly of hinge joints like the knee and elbow that are operated by the muscles, the result is a system with 100 mechanical degrees of freedom.[4] Each hinge can be characterized by two states – its position and velocity – so that we have a state space of 200 dimensions. Thus, each joint – when viewed as an agent playing a part in a larger system – must coordinate its position and velocity with neighboring agents; it is faced, in effect, with a massive decision problem.

Bringing a system of such high dimensionality into concerted action would present a formidable challenge, even more so because there is no central control. Each subsystem is relatively autonomous, subject to local demands. This was elegantly demonstrated by von Holst (1973) who studied fish whose brain and spine hand been surgically separated. The fins of these exhibited autonomous metronomic oscillations for hours after the surgery. Thus, there is no central control guiding each of the individual elements; rather the elements are acting as individual agents that are coordinating their behavior with other agents. On this level, we would expect an analogy between physical coordination within an organisms, physical coordination across organisms (as in Hume's rowing example) and social coordination where individual agents make choices that result in the emergence of a behavior or quality in a complex system like an economy. Can we extend the principles governing physical coordination within an organism to the coordination between agents in a conversation, for example?

Despite the apparent independence of the subsystems, they can cooperate to achieve an end. Action plans and intentions can be actuated by the different subsystems. These action plans are indefinite in that they leave parts of the physical implementation up to the subsystems. Action plans can be "remapped" depending on local expediencies. This fact suggests that the plans are very abstract and that the individual subsystems work out the details.

All of the above suggests that the hinges can, in some sense, be viewed as agents coordinating their action to achieve some end. In the sense, the analogy between social coordination and physical coordination seems quite close. The use of real world features to work out simple solutions to complex problems suggests that these physical systems are opportunistic and that their ultimate goal is something like the maximization of utility; here utility would mean the minimization of effort in obtaining some goal.

Social coordination, as we noted above, involves the interaction of agents who are *rational*; that is, they understand the choices available to them and to the other agents involved in the task and they are attempting to achieve the best possible outcome. While humans are not fully rational – we have limits on our knowledge and our ability to compute the outcomes of choices – some form of bounded rationality provides a good theoretical model of our behavior. Are the systems that are involved in physical coordination rational in the same sense?

Even here, there is an analogy between coordination games and physical coordination. As we noted in Section 1, solutions to games can be approximated dynamically as the evolution of conventions and conventional behavior. This sort of dynamic approach to coordination allows the participating agents to be non-rational; sub-optimal performance can be winnowed until only the best solutions, those that are in equilibrium, are left. We are still left with the problem of equilibrium selection, since not all equilibria will have the same outcomes; some equilibria might yield a highly desirable outcome with correspondingly high risk, while other equilibria might minimize risk with a less desirable outcome.[5]

As Turvey (1990) notes, a great deal of our physical coordination can be analyzed into component movement oscillators; indeed, Turvey (1990) argues that rhythmic movement is the cornerstone of a theory of physical coordination. Rhythmic movements can be composed from a relatively small number of oscillators. These oscillators are made up of an oscillatory component, an energy source that replaces energy lost through friction, a gate that admits energy to the oscillatory component and feedback system that controls the gate.

This kind of dynamic system introduces the notion of an *attractor*, a preferred state (or sequence of states) that the system will gravitate into from any arbitrary starting condition or following arbitrary disturbances to the system. Equilibrium states in social coordination games are attractors; when the game is played by a large number of agents whose individual fitness depends on the outcome of their choices, the system will be drawn to equilibrium states.[6]

A simple example of this occurs when you oscillate your index fingers at a common frequency. Notice that you can either move your index fingers in-phase (both up and both down at the same time) or out-of-phase (one down and one up). Intermediate phase-relations are not equilibria. Furthermore, when the frequency of movement is increased, out-of-phase movement switches to in-phase movement. In-phase movement never transitions to out-of-phase, and the out-of-phase to in-phase transition is not reversed when the movement is slowed back down (Kelso et al. (1986); Scholz et al. (1987)).

As with the coordination games in Section 1, there are multiple equilibria with one equilibrium state being a strong coordinating point. It is interesting, for our purposes, to note that this effect can be reproduced between two people, when the only connection between the limbs is visual. Schmidt et al. (1990) took two seated people who were told to oscillate a leg, with the goal of either in-phase or out-of-phase coordination, while the frequency of the movement was increased. To accomplish the task, the two subjects had to watch each other closely. Once again, there was a sudden behavioral transition from out-of-phase coordination to in-phase coordination as frequency increased. No such transition occurred if the subjects were not watching each other. The phase transition depended on visual communication between the subjects.

3. Language, thought and gesture

Let us turn, now, to some general connections between language, reasoning and motor coordination. There is ample evidence that gesture can influence cognition in non-trivial ways. A recent example is a study by Beilock and Goldin-Meadow (2010), who had subjects solve a four-disk Tower of Hanoi problem. The subjects were then led into another room and asked to explain to a confederate how they had solved the problem. Subjects were encouraged to use their hands while offering the explanation. They were then returned to the first room, where they solved a four-disk Tower of Hanoi problem. Some participants solved the same version as the first round, but others were given a four-disk Tower of Hanoi which had the weights of the disk reversed; that is, the smallest disk weighed the most and the largest disk was the lightest. When the smallest disk weighed least it could easily be lifted with one hand, but when it weighed the most, both hands were required to lift it.

Notice that disk weight is not relevant to solving the Tower of Hanoi problem, but it does influence the gestures that subject made when explaining the solution of the task. Some subjects made one-handed gestures in their explanations; these subjects took significantly longer to solve the Tower of Hanoi with the weights switched than subjects who had used both hands. For the group that solved the identical Tower of Hanoi there was no relation between the percentage of one-handed gestures and any change in performance between solving the first Tower of Hanoi and the second. Beilock and Goldin-Meadow (2010) suggest that gesturing hand changed the participants' mental representation of the task.

Subjects who had gestured with one hand mentally represented the smallest disk as a light object; this representation was incompatible with the weight of the disk in the switched Tower of Hanoi. Note the relationship, here, between gesture and coordinated movement. In general, ballistic movements are a form of coordinated gesture with many degrees of freedom (Turvey (1990)). Notice that gesture is crucial to the representation of the problem to the participants and, therefore, played an important role in their ability to describe their solutions; there is some sense in which gesture and coordinated movement cannot be neatly severed from thought and communication.

In order to make sure that gesture was, indeed, the crucial parameter, Beilock and Goldin-Meadow (2010) ran the experiment on another group who were not asked to explain the solution to the Tower of Hanoi but, rather, were given a passage to read and then answered questions related to the passage. It was virtually impossible for subjects to explain the solution to the problem without gestures, so Beilock and Goldin-Meadow (2010) settled on the passage-reading as a way of eliminating task-related gestures. They noted that subjects in this experiment solved the second Tower of Hanoi faster on average, regardless of what group they were in. Reversing the disk weights did not affect performance.

The question is how crucial coordinated gesture is to performance, both in terms of communication and in terms of the general representation of the task. Cook and Tanenhaus (2009) demonstrated that simply watching another person's gestures can have an impact on the watcher's performance. Participants were asked to watch either spontaneous gestures that mimicked the way that Tower of Hanoi disks are really lifted or ones that simply traced the trajectories of the disks. They were then asked to solve a Tower of Hanoi task on a computer. Subjects who saw gestures mimicking the actual movements were more likely to make the computer disks follow real-world movements – they lifted the disks over the pegs. Subjects who had simply watched the trajectories were more likely to move the disks laterally from peg to peg. In other words, the watchers' representations were influenced by the gestures they saw. It seems that physical coordination, in the guise of gesture, is fundamental to the act of social coordination; in using gesture to communicate, the speaker fundamentally impacted the viewer/hearer's approach to and understanding of the problem.

The Cook and Tanenhaus (2009) experiment shows coordination across individuals that can influence problem solving. Evidence form Woolley et al. (2010) suggests that group intelligence can actually differ from individual intelligence. They first assigned subjects to 40 three-person groups which worked together for up to 5 hours and a variety of simple group tasks as well as a more complex criterion task. The tasks involved solving visual puzzles, brainstorming, making collective moral judgments and negotiating over limited resources. The criterion task involved the group playing checkers against a computer opponent. The results supported the hypothesis that there is a general collective intelligence factor in groups and, furthermore, the average and maximum intelligence scores of the individual group members did not significantly correlate with the collective intelligence factor.

In a follow-up, they replicated the initial results and used a more complex criterion task, an architectural design problem. The average and maximal intelligence of individual group members was only moderately correlated with the group intelligence factor, which was the best predictor of overall performance. First, there was a significant correlation between group intelligence and the average social sensitivity of the group members.[7] Second, there was a negative correlation between group intelligence and the number of speaking turns by group members; when a few people dominated the conversation, the collective intelligence was lower. Finally, group intelligence was positively correlated with the number of women in the group. The collective intelligence of the group hinged on the composition of the group and the way in which the group members interacted, suggesting that coordination between members is a crucial factor in group intelligence.

Shockley et al. (2009) report on a number of experiments that suggest that physical and conversational coordination are intimately related. In one study shared postural configurations of pairs of people engaged in a conversation were measured by their postural sway. Subjects were given a puzzle task in which subjects had to discover whether they were looking at the same picture. Since each could not see the other's picture, they had to discuss the pictures. Subjects were allowed to converse and gesture freely. To control for the influence of vision, subjects were either oriented toward their partner or away from him. Participant pairs that performed the task together shared more postural configurations and maintained similar postural trajectories longer than subjects who were paired with an experimental confederate.

The effects of coordination can even be measured by eye-movements and gaze. Subjects sharing common ground and background information show significantly higher gaze coordination than subjects who had been given different information. Crucially, the effect holds when the subjects have the same information and know this to be the case (see Richardson et al. (2007)).

Shockley et al. (2009) argue that interpersonal coordination can be treated as a self-organized assembly of units that can be thought of, at least temporarily, as a single functional unit. In particular, the account of this assembly is largely the same as the account of motor coordination. This suggests that social coordination, particularly linguistic coordination, is subject to the same principles as motor coordination. When coordinating our behavior we became, as it were, a single, virtual body, constraining each other using both visual and verbal signals. As we coordinate, our different aspects of our actions can become more alike.

4. Conclusions

Garrod and Pickering (2004) have argued that coordination comes from the interactive alignment of conceptual representations. Alignment occurs at a variety of levels including lexical choice, syntactic encoding, intonation and pitch. Shockley et al. (2009) suggest that these alignments arise on analogy with motor coordination. Coordination in language can be analyzed the same way that coordinated movement is analyzed, in terms of oscillators and attractors. Shockley et al. (2009) argue that the type of spontaneous alignment described by Garrod and Pickering is not special to cognitive linguistic systems, but can be observed throughout physics and biology when units coordinate. On this view, then, alignment can be derived as a special case of a more general physical system, one that can also be used in accounting for social coordination; while other principles might be required in the various cases, the underlying systems are the some.

A more general approach would hold that social coordination of the sort we began with can be analyzed in the same terms as motor coordination. We can frame the research program in terms of two broad areas of research, one synchronic and one evolutionary:

(2) Can social coordination – in particular, language – be described solely in terms of motor coordination? That is, is there a general study of coordination that includes both social coordination and motor coordination?

(3) Did social coordination arise evolutionarily out of motor coordination? That is, in bringing their behavior into harmony, do animals coordinate their motor behavior? Can this coordination be used, then, to explain the origins of language and social coordination?

We saw that equilibrium states in coordination games can function as attractors and that attractors are crucial for understanding motor coordination. We would then hypothesize that social coordination, linguistic behavior and motor coordination are, properly speaking, subject to the same abstract constraints. With time, behavioral game theory, linguistics, and the study of motor coordination should converge to reveal the underlying principles that regulate these superficially divergent systems.

We have considered, here, some broad and suggestive analogies between physical coordination in individuals, as it is understood in psychology and physiology, and social coordination as understood in game theory. In both cases, agents must bring their action into synch with each other. It is time to open a dialogue between students of social coordination on the one hand and physiologists and psychologists interested in motor coordination on the other. As we have seen there are links between language and gesture as well as links between eye-gaze and communication.

There are, however, reasons for caution as well. Language involves symbolic representation in a way that motor coordination does not. These symbolic representations exist as a further level that can influence social coordination. Equally, while joints might be said to have interests – not twisting in directions that cause pain and so on – and their interests might sometimes come into conflict – the joints might have to accomodate the positions and velocities of their neighbors – their interests are, in the end, physical and determined by physics and bio-mechanics in a way that an agents social interests and goals are not. Social agents can have abstract ends that are not neatly accommodated by physical reductionism. Thus, there is a question of agency here that needs to be explicated precisely. My wrist is not a full agent in the sense that I am!

Despite these cautionary notes, there is a broad consonance between the study of social coordination and physical coordination. It is time to explore a synthesis between these fields.

Notes

1. Turvey (1990) is larger concerned with physical movement and the relationship between physical coordination and other physical processes; the hypothesis we are interested in is slightly different. Namely, the principles that guide physical coordination can be applied fruitfully in the study of social coordination and cognition.

2. Theory of Mind (ToM) has been the subject of intense investigation in psychology. A useful summary is provided in Baron-Cohen (1997).

3. There is some debate over whether rationality implies selfishness and what, exactly, this means. Sigmund (2010), Nowak (2006) and Nowak and Highfield (2011) have a stimulating discussion of this issue. For space reasons, I will simply sidestep the issue and simply note that there is some evidence for "team reasoning" as discussed in Bacharach (2006).

4. I relay here mainly on the survey by Turvey (1990). Kelso (1995) has become a standard reference. Kelso and Jirsa (2004) present a sampling of more recent research.

5. See Harsanyi and Selten (1988) for a formal discussion of equilibrium selection. Skyrms (2004) gives a good discussion of the problem of equilibrium selection in the evolution of conventions.

6. See Gintis (2000) for a general discussion of this point.

7. Measured by the "Reading the mind in the eyes" test. This test asks subjects to judge emotions by looking at photographs of individuals' eyes. See Baron-Cohen et al. (2001)

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