9. REFLECTION AND ELABORATION

In the previous chapter I synthesized the results of micro and macro-analyses to develop several findings with regard to various ways in which persistent shared representations take part in productive design activity. I proposed a comprehensive framework for representational support, and several dynamics through which it was possible to characterize the work performed by representations in real-time design interaction.

In this chapter I take stock of how successfully the research has met its objectives, and discuss possible directions for further work. Critical reflection on methodology provides a starting point from which to consider more refined questions, enhancements, limitations and theoretical implications of the perspective I have developed.

Methodological Issues and Reflection

The purpose of this research has been to deepen our understanding of the involvement of persistent shared representations in situated, collaborative design. The approach involved fine-grained analysis of communicative acts and representational activity associated with collective design reasoning. This sheds light on the essential interactional work of collaborative design: a process of synthesizing perspectives, reconciling differences and consolidating commitment to action intended to bring about a preferred future.

The specific objective was a perspective and an analytic method to highlight the work performed by shared representations in design with the potential to inform other settings and contexts. The results have included a comprehensive framework for representational support and a way of looking at design interaction that is integrative and addresses gaps between prominent theoretical perspectives regarding this type of activity. The framework provides a way of understanding the state of support in any situation and ways in which it might be improved. The perspective suggests more refined questions, provides a method that will be useful in subsequent hypothesis testing, and has implications for extant theorizing on several levels of analysis.

On this basis I believe the study has met its objectives. In keeping with its exploratory nature however, a number of issues have arisen that provide impetus for improvement and further work. As a starting point, I will now shift to more critical reflection on methodology, first by revisiting other aspects of study quality as raised earlier in Chapter 3.

Study Quality Revisited

Yin (1994) presents several criteria for evaluating case study quality, including construct validity, internal validity, external validity and reliability. I will summarize each below, and then elaborate on problematic areas that suggest issues, opportunities and potential limitations.

Construct validity requires that the analytic constructs are appropriate and adequate to address the phenomena present in the data. In developing the micro-analytic approach, I reviewed a range of previous observational coding schemes and employed exploratory coding of a large number of episodes to determine which distinctions were most applicable to my data. I introduced additional categories and refinements as required by a micro-analysis of episodes selected to offer the most informative contrasts. These were ordered to introduce complexity in stages, with iterative re-coding to ensure consistency. I found certain features of network structure and discourse composition provided an effective means of identifying productive patterns of interaction across the selected episodes. Combining this with macro-analysis of developments over longer time scales yielded a set of coherent constructs regarding representational support across a range of time scales, within the overall formalization of an actor-discourse network. On this basis I believe adequate construct validity has been demonstrated.

Internal validity reflects the robustness of causal assertions made on the basis of correlations in the data. Because of the exploratory stance of this research, testing of causal hypotheses was not an objective, hence the criterion of internal validity is not strictly applicable (Yin 1994).[188] It is still appropriate to consider the validity of the relationships I proposed between network metrics and favourable aspects of interaction (and hence the implications for conversation quality). In this regard I found one metric to be robust; the second was informative but problematic in some respects. To address this weakness, I proposed a new metric as a more appropriate index for mutual engagement.[189] I also offer a number of suggestions for subsequent, hypothesis-testing research below.

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[188] Exploratory case studies are designed to provide more useful insight in situations where relevant phenomena are not yet well-enough understood to warrant the testing of specific hypotheses with regard to causal relationships. Exploratory studies should meet clearly-defined objectives and give rise to better, more refined and potentially testable questions—as this study has done. (The latter are detailed below).

[189] Some difficulties with discourse betweenness as an index of mutual engagement stem from behaviour of the flow betweenness centrality metric under certain circumstances, described in Chapter 6 and detailed in Appendix C. An alternate approach to assessing mutual engagement is described in Appendix E. Overall, discourse betweenness did appear to usefully discriminate between the positively and negatively selected episodes.

External validity reflects the likelihood that findings can be generalised and usefully applied in other cases. I argue it is positively indicated by three aspects of this work: (1) general applicability of the perspective and the utility of the roles and attributes framework to evaluate representational support in collaborative design interaction; (2) at the level of collective design reasoning, an integrative extension of theory and method that conveys the ability to ask more refined questions; (3) at other levels of analysis, consistency with the boundary conditions presented by extant theorizing. As I discuss in more detail below, while I believe this perspective has broad applicability, by no means does it encompass all phenomena that may be important in collaborative design.[190] Accordingly I anticipate several issues with regard to analytic generalization, and discuss these in terms of opportunities for further work and potential limitations of the approach.

Finally, *reliability* requires confidence that errors and bias have been minimized. As a concept, reliability is distinct from replication.[191] In research involving coding schemes, reliability is often framed in terms of the consistency with which a coding scheme can be applied by other researchers—though there are differences of opinion about the importance of this criterion (cf. Nyerges et al. 1998 and Morse 1997). In case research, since literal replication is seldom an option, reliability more often rests upon straightforwardness of method and clarity of description (Yin 1994). Would the coding scheme have benefited from having a second researcher attempt to deploy it on the same data? On balance I think it would have, had this been practical.[192] The essential question is whether the distinctions are analytically appropriate, adequately articulated and sufficiently non-arbitrary to be usefully applied by others. Toward that end I have tried to be as explicit as possible and have provided abundant detail in appendices. I hope this work exhibits the necessary thoroughness, clarity of method and quality of documentation to afford analytic generalization and theoretical replication by others.

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[190] On the whole, I argue that the method usefully highlights the involvement of representations in task processes, and allows correlation with other (e.g. socio-emotional) processes assessed orthogonally or in conjunction with other means.

[191] Though literal replication is an indication of reliability, the two are distinct concepts. As Yin (1994) makes clear, the primary mode of replication in case research should be theoretical rather than statistical. Theoretical replication is achieved when the results of subsequent cases are shown to be consistent with a particular perspective and not consistent with others.

[192] As discussed below, interpreting utterances as referring to or being about the same thing is an essential analytic judgement. For real world interaction in a complex technical domain, these determinations would be difficult for an analyst to make without benefit of the many hours of observation, follow-up and contextual interviews that comprised the data collection. In this research, one other investigator took part in observations and participated in the early qualitative analysis. Because this researcher's objectives were substantially different from mine, it would not have been possible for her to expend the redundant effort required to learn and apply the coding scheme I developed.

I will now elaborate on issues of analytic generalization, including opportunities, possible extensions, and limitations of the approach I have developed. To address potential reliability issues, I will also reflect on problems I encountered in coding and analysis and improvements that may be undertaken in further work.

Issues and Limitations on Analytic Generalization from this Setting

How likely is it that the approach I have described can be generalized, and what issues may be encountered in applying the analysis to other settings? Though the data I used in this research are drawn from a particular setting, I have endeavoured to formulate concepts in terms that will allow them to be applicable and relevant to design activity more generally. I believe the notion of alignment (the basis of the spatial metaphor PROXIMITY=AFFINITY in the network formalization), reflects an essential aspect of collaborative design interaction in many situations, wherein success depends upon achieving collective commitment and coordinated action.[193] I believe the categorical distinctions embodied in the coding scheme are sufficiently general to be usefully applied—if not comprehensive—in other settings and contexts. I recognize that particular characteristics of the setting may, however, have an impact on analytic generalization. These include:

- a relatively structured and patterned process with a leader and team members with clearly defined roles and agreed-upon boundaries of expertise
- a highly technical domain involving complex but deterministic phenomena amenable to modelling
- an engineering design discourse emphasizing rational argument within a problem solving paradigm
- primarily conceptual design activity excluding a number of non-design functions (e.g. manufacturing, sales, marketing)—and the attendant diversity of "thought worlds" (cf. Dougherty, 1992)—that might be encountered in other settings[194]

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[193] The coding scheme is essentially based on alignment as an index of an individual's expression of commitment to particular solutions and other aspects of design reasoning. The spatial metaphor is therefore a meaningful interpretation of network distance in a mathematical sense, apart from any particular visualization. Structural network metrics were used as a way of transcending the limited reliability of visual interpretation of 2D layout diagrams alone, as I have discussed in Chapter 5 and detailed in Appendix E. My conclusions about the relationship between network structure and aspects of design interaction are based upon a combination of these numerical metrics and visualizations constructed to minimize layout problems, bearing limitations of the latter in mind. I use the overall correspondence between network structure (assessed in this manner) and relevant aspects of interaction to validate the coding scheme and network formalization for design activity. While the precise details of network structure depend upon certain decisions, such as regarding the relative duration of arcs, I have articulated my reasoning and the relevant considerations, endeavoured to be consistent, and undertaken sensitivity analyses where appropriate to ensure the results are not unduly dependent upon arbitrary decisions.

[194] This is the type of situation likely to make the actor-network processes of *translation* more visible and problematic. Bringing such diverse perspectives into real-time interaction will, however, create opportunities for mediated convergence along the lines I describe in Chapter 7.

I will briefly qualify each of these characteristics before elaborating on the issues and limitations I foresee. With regard to deterministic phenomena and the use of modelling, other design fields also have their own distinct, persuasive representational practices. Many practitioners now employ computer-based tools alongside more traditional media. I have attempted to formulate my conception of representational support in terms of roles and attributes that are relevant and sufficiently general to encompass this diversity of practices.

It is also true that decades of experience in aerospace design at JPL establish a basis for substantial common ground amongst participants with regard to the ways in which design projects unfold. This is an environment, however, in which every project involves a significantly novel undertaking, continually introducing new voices and new knowledge.[195] In addition to the leader and standing team, the design process involves the differing perspectives of scientists, technology developers, other agency customers and program managers. While this diversity is perhaps not the same as one might encounter elsewhere, it does allow for significant differences of opinion and conflict to arise. All participants can, however, be expected to engage in and respect the terms of an engineering/scientific "object-world" discourse (Bucciarelli 1994).

As I discussed above (in Chapter 2) the JPL setting foregrounds task work processes over other, more socio-emotional processes. I argue that this has presented an opportunity to make representations' involvement in task work processes particularly visible. (Indeed, rather than being incidental, this may be an essential contributory factor to the outstanding performance of these teams.) However, socio-emotional work may be equally important—even decisive—in other settings of collaborative design. This has implications for generalization and applicability which I will now review, identifying the characteristics of situations I believe will render the method more or less useful.[196]

Direct Application

Based on characteristics of interaction in the setting and the data I was able to collect, the observational method I present here is likely to be directly applicable to design situations with the following characteristics:

- interaction that is substantially verbalized, as opposed to predominantly implicit or relying on non-verbal communication

[195] JPL's charter within NASA involves addressing the risks and challenges of one-of-a-kind exploratory space missions; the environment is therefore one in which profound uncertainty and innovation are essential aspects of routine (O'Donnell 2002, NASA undated JPL fact sheet).
[196] As I will discuss in a later section, the theoretical perspective may still have useful implications even in situations where the observational method is not directly applicable.

- design discourse that emphasizes explicit reasoning over more purely affective responses
- conversational contributions that, on the whole, are specifically directed and clearly pertain to particular discourse elements or features of representations

Overall, such interaction can be characterized as predominantly *rational* and *lexical*. More generally, it will be important to take socio-emotional processes, individual and collective affect, other discourses and communicative modalities into account, since these may play essential or decisive roles in other settings.[197]

Use in Conjunction with Other Methods

Essentially, the approach I have described constitutes a lens. It can be used to analytically represent the accomplishment of *task* work that is enacted through individuals' expression of differential alignment in discourse, accompanied by some form of negotiation to obtain consensus and commitment. By employing orthogonal observational methods and coding schemes for socio-emotional processes and affective expression,[198] the relationships between these and task accomplishment can be analytically investigated. Along these lines, I propose several follow-on questions that can be addressed in further work in the following section.

Different conceptions of collective reasoning may also be accommodated by reformulating categories for discourse nodes within the overall formalization. In general, the observational method I have presented can be analytically useful and should provide complementary insight in conjunction with other methods for the following types of research questions and design situations:

- questions concerning status or group dynamics, situations of actively contested status or group formation
- questions concerning tone or group affect, situations in which contributions are more overtly affective in nature
- questions concerning tension or conflict, situations in which responses are more personally directed or involve strong feelings, such as enmity or evident antipathy, between actors

[197] I have not excluded affect and non-verbal interaction entirely; excitement, enthusiasm and expressions of satisfaction or frustration were among the criteria for episode selection. Certain gestures and physical movements in the space were coded to reflect increased levels of engagement, though these were generally in categories assigned a shorter duration in the coding scheme.
[198] Regarding coding of socio-emotional processes in groups, cf. SYMLOG (System for Multiple Level Observation of Groups), Bales 1970, 1999, as well as the system for coding enacted status presented by Owens (1998); regarding affective coding cf. FACS (Facial Action Coding Scheme), Ekman & Friesen 1978, SPAFF (Specific Affect Coding System), Gottman et al. 1996, Giese-Davis et al. 2000.

Limited Applicability

Some basic assumptions may impose more fundamental limitations on the applicability of the observational approach. First, I assume a basically constructive orientation on the part of participants, with a relative transparency of their intentions and motivation. While strong disagreements may occur, I assume participants are not engaging in intentional deception or antagonistic to the point of formulating their arguments solely to undermine each others' positions. As a reflection of the quality of design conversation, alignment expressed in communicative acts becomes irrelevant if what participants say bears no relationship to what they believe or what they intend to do.

An additional limitation on the network formalization arises from the basic assumption that shared experience of interaction can reliably be taken as knowledge in common. The network representation primarily on the basis of observable behaviour, not as a reflection of what any member of a group might be thinking.[199] The notion of distance between actors in a singular network space (albeit one of high dimensionality) are only significant when all key actors, at least arguably, have access to the same interactional events. This is justifiable in a synchronous, real-time design environment (though as we saw, vagaries of attendance and attention will remain an issue).[200] As interactions become more distributed and asynchronous, representing collective reasoning with a singular network will be increasingly problematic.[201]

Another basic assumption in the actor-discourse formalization is that participants' substantive contributions can be localized to elements of discourse. I discuss below the possibility of elaborating the formalization in areas of non-verbal and affective communication (in conjunction with the salience and impact of contributions). However, non-specific affective responses or behaviour, such as might reflect the overall tone of participants' engagement, are probably best assessed by other means. Similarly, the network representation becomes cumbersome and inappropriate when communications are

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[199] It was not possible to interview participants immediately following interactions to query what they might have meant by any particular utterance. Some inference beyond strictly what was said was necessary in order to construct networks that adequately reflected the coherence and connectedness of conversation; this was conservatively limited to what interlocutors might infer under normal circumstances based on actual behaviour (as discussed in Chapter 5). Numerical assessments of network structure were made so as to exclude some of the more speculative judgments, such as those regarding semantic associations.

[200] At least in closely coupled, synchronous interaction, significant misperceptions are more likely to be detected and remedied by participants, as compared to decoupled, predominantly asynchronous interaction.

[201] Though it is potentially a combinatorial problem, this does not preclude the possibility of maintaining separate networks for every significant subset of closely-coupled interactants.

essentially "broadcast" and/or in situations where individuals acquire an attribute or have a certain type of experience primarily as a result of their physical location.[202]

In summary, the utility of the observational approach I have presented may be more limited in situations characterized by:

- adversarial relationships in which participants lack a fundamentally collaborative orientation and/or are likely to engage in intentional deception
- predominantly asynchronous, distributed settings in which key participants' interactions with each other cannot reliably be taken as a basis for common ground for the larger group
- interaction that is predominantly non-specific, non-verbal, non-lexical, or which relies very heavily on participants' tacit understandings[203]
- interaction in which the essential notion of task work described above is not relevant

Problematic Aspects of Coding and Analysis

In carrying out coding and developing the micro-analytic approach, I found certain judgements continued to be more subjective and/or more complex than others; accordingly, it seems the following are points at which reliability issues seem most likely to arise:

- *parsing of episodes with overlapping and interwoven topics* Though all the roles and attributes of representational support I describe have manifestations in the actor-discourse network formalization, they were not entirely visible through microanalysis alone. For this reason it will be necessary to consider how longer and discontinuous periods of interaction might be analyzed, striking a balance or synthesizing aspects of micro and macro-analyses.
- *coding instances of talk as referring to "the same" thing* This is the essential analytic judgement necessary to construct an actor-discourse network. While some theorists would say we can never truly speak about the same thing, as a practical matter I relied on background knowledge and participants' behaviour to indicate when they undertook to speak about the same thing, and felt they were doing so to a degree adequate for their purposes at hand. The fact remains however, that people sometimes act as though they are speaking about the same thing when they are aware that, perhaps to a significant extent, they are not; conversely, people who share a great deal of common ground may use different lexical forms to refer to "the same" thing in ways that could escape the analyst.

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[202] This situation could arise with regard to physical spaces that tend, on the whole, to foster creative or productive interactions (cf. Hillier 1996, Hillier & Hanson 1984, Penn et al. 1999) or "cultural" knowledge transmission that is diffuse and difficult to observe. The latter might more accurately be represented as a *field* rather than a network, wherein entities acquire an attribute by virtue of their position in space.

[203] Entirely non-verbal drawing interaction could nonetheless be analyzed in terms of an affinity network so long as the drawing surface itself provided a means of localizing contributions.

- *incompleteness of reference and indexicality of ordinary talk* People communicate effectively without explicitly spelling out the full extent of the references they intend.[204] Participants with substantial common ground in close collaboration use truncated utterances with a great deal of implicit deixis. In coding, I invoked the minimum number of nodes I felt were necessary to account for the "connectedness" of discourse between adjacent contributions, limiting carryover of implicit references to a single turn. Because these judgements have a direct impact on network metrics however, consistency is essential for comparisons to be meaningful.
- *complexity of tracking and updating semantic network relationships* Participants' contributions often embody different semantic relationships between overlapping discourse elements—particularly when they are disagreeing. Registering multiple actors' contributions—which may be at odds with one another—in a singular semantic network proved difficult within the logic of the SoNIA representation. It also significantly increased the number of decisions required (and hence opportunities for inconsistency) in coding.
- *coding of inscription* Within a rather limited logic to govern arc behaviour, a number of arbitrary decisions were required to determine the strength, duration and timing of inscription codes, distinguishing between acts that ranged from casual reference to active drawing. I made these decisions to preserve an overall parity between human and representational actors. Parity, however, does not denote equality. Besides desiring a better empirical grounding for these decisions, a more complex logic may be necessary to adequately reflect representational "speech" (as discussed below).
- *inappropriate root metaphor of flow betweenness metric* The flow betweenness centrality metric is based on a conception of nodes as potential control points for information flow in homogeneous networks (i.e. networks having only one type of actor). This metaphor is inconsistent with my conception of shared discourse elements as bridges between participants. Rather than engage in a lengthy process to characterize the behaviour of this metric more fully, I proposed a new metric that I feel more directly assesses mutual engagement, with the additional benefit of optionally utilizing the semantic network in structural assessments.

These problematic aspects encountered during coding and analysis suggest a number of possible technical developments that could be undertaken for further work, including:

- changes to enhance the content and reliable interpretation of 2D layout diagrams
- a more complex logic to govern arc aggregation and temporal behaviour of arc strength
- a layout procedure to minimize artefactual movement in animations
- a metric for mutual engagement based on an electrical conductance analogy

These are described in more detail Appendix E.

[204] This is an essential insight of ethnomethodology, cf. Garfinkel 1964, 1967 and in Suchman 1987

Elaboration for Further Work

To be judged a success, an exploratory case study should meet its objectives *and* give rise to more refined and potentially testable questions (Yin, 1994). Based upon the issues and problematic aspects identified above, I propose the following directions for elaboration in further work. These include testing of follow-on hypotheses that can be addressed through the method I have developed, either alone or in conjunction with other methods, as well as certain extensions of the formalization that may be required to make the method more useful and do justice to other settings.

Refined Questions and Follow-on Hypotheses

As I outlined above, with appropriate data collection[205] and complementary observational methods, the approach I have presented can be used to explore more refined questions and to test follow-on hypotheses. Essentially, the method allows the accomplishment of task work to become a criterion variable in studies investigating hypothetical relationships with various other (e.g. socio-emotional) processes.[206] The network-based approach provides an inherent consistency with a number of other constructs amenable to social network analysis, including status, expertise and social capital.

The following are types of research questions for which specific hypotheses could be formulated and tested:

- In terms of role, status, expertise and credibility, how do formal designations compare with enacted behaviour in different situations? What behaviours appear to impact participants' assessments most decisively?
- In what ways are remote participants potentially disadvantaged? How does the composition of discourse and the character of interaction change as more participants are remote?
- With regard to the composition of discourse, engagement of expertise and use of representations, what decision quality constructs are appropriate for design reasoning in different situations?

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[205] This includes sufficiently detailed observational (i.e. video) data and adequate access to interview participants in detail about their perceptions, thinking and subjective experience of interaction.

[206] In this exploration, I utilised concepts from actor-network theory. This generally argues for a balanced treatment of human and non-human (i.e. representational) actors; accordingly, I performed my analyses on networks that included inscription and representational acts, to maintain parity with communication directly between human participants. For subsequent hypothesis testing however, if representational acts and mutual engagement are employed as predictor and criterion variables, it may be advisable to define mutual engagement only between human actors. This would eliminate a potential circularity whereby inscription can directly increase mutual engagement in the analyses I have presented.

- Under what circumstances are disagreements and tension productive? How do participants regard those with whom they disagree, as related to the substance or form of the disagreements?
- What is the relationship between participants' engagement and co-construction of representations, and their commitment to the outcomes the representations are understood to embody? What are the social effects of successful joint action in a representational domain, compared to other forms of joint action?

Extension of the Formalization

The network formalization allows for the creation of a record of observable behaviour that can be visualized and queried using numerical techniques. Construction of these representations has been a form of modelling.[207] In this spirit, working within the formalization has raised certain questions that, if better understood, will convey additional insight and facilitate further elaboration.

Registering the Impact of Contributions and Dimensions of Representational "Speech"

In the network model, arcs correspond to communicative acts of various types, and relationships between actors are primarily mediated by elements of discourse. The coding scheme was adjusted to foreground what I identified as design discourse, de-emphasizing other acts and neutral exchanges of information. In this admittedly lexical view of interaction, the parity suggested by actor-network theory essentially requires that representations are endowed with a capacity analogous to human actors' speech. How might this metaphor be taken further?

Arc behaviour is currently governed by a rather straightforward logic, wherein each arc has a fixed strength and duration, and multiple arcs between the same nodes are either summed or averaged; otherwise, arcs are completely independent of one another. As I mentioned above, more elaborate coding for non-verbal communication, and/or affectively-laden acts directly between participants may be required to reflect the impact of their contributions.

More generally, what determines the salience, impact and memorability of any particular contribution, and how important is subsequent social acceptance (and by whom)? Specifically, how should this translate into *inscription*, in terms of the parameters of the network representation (e.g. arc strength, duration)? As a direction for technical development, I would propose a more elaborate logic to allow an inscription's strength to respond to more than just the initial act that created it. It seems reasonable that a variety of

[207] Snodgrass & Coyne (1992) discuss the essential utility of models (as a subset of metaphors) in terms of their ability to stimulate cycles of interpretation and re-interpretation.

factors may come into play, including the way other actors subsequently engage, who they are, their status in the group, etc.

I formulated the concept of representational support in terms of situational attributes that essentially describe the involvement of representations as network effects. An obvious next question is, what intrinsic properties may impact any particular representation's ability to afford these situational attributes? Are there properties of media or other aspects of structure or configuration that make some representations inherently more compelling and convincing, or are these situationally determined as matters of practice? What might be necessary to account for the particularly compelling nature of prototypes (highlighted in Chapter 1, and a subject to which I return briefly in the concluding chapter that follows)? I used the term "autonomy" to refer to representations, such as simulations, that when set in motion operate subject to their own internal rules as a credible proxy for reality. Are other attributes like "totality," "fidelity" or "verisimilitude" necessary to account for complexity, detail, or the way some representations leave less to the imagination? Conversely, are representations that leave *more* to the imagination particularly powerful in other ways?

I intend this discussion to pertain primarily to the collective level of design activity, since this has been the focus of this research. By no means do I intend the situational attributes I proposed at the more individual or organizational levels to be exhaustive. It may be that engagement on an essentially affective level comes into play as well, perhaps in a manner analogous to person perception. How we feel about a representation may impact how receptive we are to what it has to "say." While these may be distinct phenomena—i.e. we can believe something without liking it, and vice versa—the most powerful representations are probably those we both like *and* believe. Again, while it cannot answer these questions directly, the approach I have described can be used in conjunction with other methods to shed light on answers that could, eventually be incorporated in the network formalization.

Other Discourses

To explore other types of design activity, it will be necessary to embrace design discourses less dominated by rational argument, and that adhere less closely to a problem-solving paradigm than the activity I observed. I propose that, subject to the considerations and limitations outlined above, this principally requires developing new categories for nodes. In the approach I have taken, the actual composition of discourse—vis-à-vis the categories for reasoning (e.g. issues, options and criteria) is only of secondary importance. The most important aspects are alignment, mutual engagement, and closure with the commitment necessary to advance the state of the design. The precise manner in which this is accomplished, and the form it takes in discourse, can be accommodated in different ways

within the basic approach I have described. This is best undertaken in a data-driven manner, through subsequent work in different settings; consequently I will mention only a few differences that might be anticipated.

Coyne & Snodgrass (1995) discuss the ways in which different metaphors render different aspects of design activity problematic. Focusing on issues as initiators of cycles of collective reasoning, as I have done, is consistent with a problem-solving frame for design activity. Another conception of design sees it as fundamentally driven by the recognition of opportunities to expand the scope of what is possible. The Sony Walkman, for example, was not preceded by a recognized need for such a device. The Cryobot Lander Study was arguably initiated by the opportunity created by the compact high-power source.[208] Though it was not required by this data set, I would propose a fourth discourse category for "opportunity/possibility," complementing "issue/problem," as a first step to expand the scheme beyond strictly problem-solving discourse.[209]

Beyond such an incremental change, other features of design discourse can be anticipated. Visual and linguistic metaphor may be essential to access affective dimensions of objectives and criteria.[210] Iconic objects, projects and personalities may serve as essential "reference points" for reasoning more broadly construed to include narrative, and other ways of knowing that blend both affect and reason.[211] Other design discourses are likely to have different ways of making room for surprise, unanticipated connection and the departures from routine that are essential to innovation—as well as different ways of "rationalizing" these so they may be acted upon.[212] While the specifics may require different lenses, it is these dynamics that are at the heart of the formalization I have presented, and which I argue will be broadly relevant to design activity.

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[208] This took place prior to the research observation for this study, hence it is not present in the data.
[209] Even in a hypothetical design exercise, the frame of an imagined possible future rapidly becomes real as the "joint pretence" (Clark 1996) essential to the conversational project. It is within the context of such a frame that issues and problems arise and solutions are generated. An "opportunity/possibility" would denote a proposal for an entirely different frame, simply as an exciting possibility in its own right, not as a solution predicated upon an established issue or problem.
[210] Dumas (1994) describes the use of co-constructed "totems"—shared representations utilizing visual metaphor—as part of an intervention strategy to improve communication within product development teams.
[211] Lakoff (1987) discusses metonymy in conjunction with reference point reasoning, citing Rosch (1975, 1981). Bruner (1990, 1979) reflects on the diverse ways of knowing embodied in psychology and literature, to better understand the place of myth and narrative in thought and to advocate a broader appreciation of other-than-rational discourse—even within the sciences.
[212] Snodgrass & Coyne (1992) argue that scientific models and other metaphors share an essentially hermeneutical rationality rather than a logical one. McLachlan & Coyne (2001) find that such a post-structuralist account is most in accord with the discourse of avant-garde architects. For my purposes, the most interesting question is not how such architects persuade each other, but how they collaborate across discourse boundaries.

Representational Actors

The representational actors in this case were only a subset of the canonical forms of design representation. While CAD models and spreadsheets were abundant, with the noteworthy exception of some whiteboard sketching, other types of drawings and paper media were relatively scarce, and hardware and physical prototypes were entirely absent. In more general design interaction, other forms of representation will be involved and it is necessary to consider what one might wish to include as a representational actor in such situations.

By definition, actor-networks are heterogeneous. That is, they can include many things, ranging from individuals, to technologies, to organizations and institutions. Going forward, the question arises, how shall we bound the notion of a *representational actor*—particularly with regard to artefacts that share superficial attributes with common design representations? For example, in what sense might shared video monitors of real-time events (cf. Goodwin & Goodwin 1996) be considered representations? What about the simple computational artefacts and techniques that Hutchins (2005) describes as material anchors for conceptual blends, or the paper charts Goodwin (2000) describes for standardizing archaeological descriptions?[213] Conversely, artefacts like advanced prototypes may look far more like "the real thing" than any representation, yet still serve important representational functions.[214]

For my purposes, whether a particular artefact should be classed as a representation depends upon the way it is used more than any intrinsic property or attribute. Overall I have chosen to emphasize the aspect of *making present* (to the eye or to the mind) and *standing for* (in the manner of a proxy) to characterize something as a representation. Determining something to be a representational actor also depends upon the purpose of the analysis. If the intention is to understand the continuity of situated action or distributed cognition, then things like real-time displays and standards charts might properly be included as actors.

My central interest, however, has been understanding the ways in which persistent shared representations figure in *design interaction*. This involves more than coordination and computation; it requires commitment to bringing about a fictive future reality. I consider design representations to be those artefacts that stand for and make present the object of a group's collective work—a calculated intervention intended to bring about a preferred future. This would include representations of the designed artefact itself, as well as shared objects like profiles and scenarios that make present users and their behaviour. Procedural

[213] Goodwin (2000) refers to these reference charts as graphical or semiotic fields, saying they are more properly seen as spaces for the production of action rather than as representations. Of course, I am arguing that design representations can also be seen in these terms.

[214] Even production prototypes—virtually indistinguishable from final products—are experimental in that they involve anticipations or approximations of "real" processes.

artefacts, like schedules and process descriptions could also take on the roles of design representations if they have a substantive impact on design reasoning.

Other questions are likely to arise with regard to more typical design representations under different circumstances. For my purposes, for example, multiple copies or instances of "the same" representation (such as a particular CAD model or document) would be treated as the *same* representational actor (particularly if participants are engaged in closely coupled interaction)—unless substantive, perceptible changes were durably inscribed on one vs. another.[215] Conversely, one might ask, at what point would an evolving CAD model become a *new* representation? I would argue that looking at the commonality of inscribed features from one instance to the next provides the most reasonable way of making such a distinction.[216] However, when representations—even those sharing substantial features—are made present simultaneously to embody a choice between mutually exclusive alternatives, these must be treated as distinct representational actors.

Parsing, Conjoining, Collapsing and Expanding

To expand the scope of the method I have presented, it will be necessary to encompass interaction over longer time frames and across temporal discontinuities. For further work I propose two developments that will be required to make this possible. One is a less fine-grained approach to coding, so that the analysis of longer periods is not inordinately time-consuming; the other is a less-subjective basis upon which to parse interaction and conjoin related but temporally distinct episodes.

For a less-fine grained approach to coding, I propose returning to the essential cycle of collective design reasoning, discussed in Chapter 8 (and in Appendix C), that was evident in the positively-triangulated episodes. This involved some form of initiation or opening, followed by subsequent development of a problematic situation and potential solutions, leading eventually to some form of closure with enhanced design specificity and commitment. I propose that a more streamlined coding approach could be developed at the level of this cycle, with individual actors' engagement normalized in some way to reflect their alignment with respect to key outcomes.

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[215] For example, annotations on one copy of a document that became a shared referent for a subset of people in a meeting could become a distinct representational actor.

[216] Note that the process of inscription I have outlined allows a representation to assume different figurations in different contexts, by virtue of what features are identified by different actors. Over longer time frames, distinct representations sharing a substantial number of features will remain close to each other in network space, so the question of whether something should be a distinct representational actor becomes one of degree rather than kind.

This type of analysis will always require some sort of bounding, and it may be that only a fraction of the interaction in a particular setting pertains to a feature of interest. Since real-time design interaction involves a fluid shifts between topics and participants, the issue of parsing remains complex. For further work I propose that a proximity threshold for network distance can be used as a more reliable basis for many of the decisions required to analyze longer episodes and discontinuous periods, including:

- distinguishing threads on the basis of clustering of issues and actors in network space
- distinguishing between actors (both participants and representations) who participate broadly across many issues vs. those that are more narrowly focussed
- parsing on the basis of discontinuities in the temporal evolution of the network (jumps between disparate parts of the issue-actor space in the absence of any content-logic connection)
- conjoining temporally discontinuous sequences of interaction on the basis of their proximity in the issue-actor space

Another issue is how one might reconcile and merge the effects of interaction across discrete episodes and from analyses performed at different levels of granularity. For this, an approach to collapse the level of network detail to a uniform consistency may be useful. As I illustrate in Appendix E, a pair-wise closeness metric allows conversion of an actor-discourse network to one consisting only of actors.

To understand the temporal evolution of design reasoning, however, I argue that discourse should not be excluded entirely. The most productive simplification is likely to be one which retains key relationships between actors and the discourse principally associated with initiation and closure. Such a network could be obtained from the type of coding I performed by driving the strength of all semantic arcs to be very high. This would have the effect of collapsing all the discourse that pertained to a particular issue into a single node.[217] Participants' proximity to this node would reflect their overall engagement in the discussion and their alignment with the approach embodied therein.[218]

This notion of collapsing the elements of a confirmed agreement onto a singular node is essentially comparable to the actor-network processes of "punctualisation" (Latour 1986, 2005) or "black-boxing" (Latour 2005). This is one way in which the effects of jointly-accomplished work and consolidated agreement—particularly when robustly inscribed in

[217] This could provide a network formalization corresponding to Dorst & Cross' (2001) co-evolution of problem and solution spaces.
[218] This might obscure subtle defects of consensus, such as we saw in Episode 12, unless these were registered in other ways.

representations—might stabilize constellations of actors around a particular design approach. Understanding design in terms of the temporal evolution of such networks leads us to some explicit theoretical elaborations which I will now discuss.

Theoretical Implications

The review in Chapter 2 highlighted several discrepancies between the prominent theoretical perspectives that address situated work interaction around shared external artefacts and representations. The situated action perspective is characterized by close attention to artefacts and fine-grained interaction analysis. Its focus, however, tends to be on relatively low-level coordination processes and behaviours which, despite their importance, are somewhat removed from practitioners' consciously-formulated instrumental concerns. Along with a certain scepticism toward the notion of representation, this remove makes it difficult to relate situated action analyses to a relevant theory of performance for design. Distributed cognition also devotes close attention to artefacts in interaction. Out of a desire to speak authoritatively about internal mental processes however, it tends to focus on highly structured interaction and essentially computational tasks that bear little resemblance to design.

Activity theory delves into the relationships between subjective awareness, motivation, and the socio-cultural-historical patterns embedded in tools and artefacts. By emphasizing the constituent structure of each activity system however, the framework becomes somewhat cumbersome when it comes to interaction at the *intersection* of activity systems. An explicit stance to disregard any distinction between that which is internal vs. external to individuals also makes the perspective problematic for design interaction, where external representations are of obvious and undeniable importance.

Actor-network theory (ANT) addresses precisely this intersection of activities, but focuses on points of contention, coordination and the dynamics of allegiance to delineate the relevant structure of the systems involved. This makes it a useful perspective with which to understand change and technological innovation. However it offers no detailed account of how essential processes (i.e. translation, conscription, punctualisation) are actually manifest at the level of interaction, or how they are accomplished through interactional work. Whereas activity theory accounts for innovation as a result of internal contradiction *within* systems, actor-network theory depicts it as a result of tension and competition *between* systems. In design, innovation involves both competition and creative collaboration, so it seems reasonable to attempt some sort of synthesis.

Constellations of Issues and Actors

In my conception of representational support I have tried to account more explicitly for the essential involvement of design representations in this range of processes. By making actor-network concepts operational at the level of interaction, in terms of alignment—and by treating representations as actors, I have synthesized a triadic communication model comparable to that embodied by the situated action and distributed cognition approaches. Drawing upon aspects of activity theory that better account for individuals' motivations, I have offered an account of how conscription operates through individual actors' proximal concerns, their collective reasoning, inscription, and attributes of representational credibility and robustness.

Essentially, this leads to a view of design activity in terms of temporally evolving constellations of issues and actors, in which representations act to mobilize and anchor networks of commitment. Ultimately, this approach provides an answer to what it is that is *created* through design collaboration—particularly in the case of commercially meaningful innovation. I argue that it is these constellations—their order, stability and robustness—that is the essential product of collaboration. Achieving the necessary alignment of actors and a configuration of representations that will enable such a constellation to enlist an expanding network of allies *is* the interactional work of collaborative design.

With regard to collaboration, this framing helps us avoid difficulties with treating *ideas* as outputs, and getting mired in questions about whether one outcome is *more creative* than another.[219] Instead, we can characterize outputs in terms of the span of the networks that are created, and the resources they are able to marshal. This maintains a fundamental consistency with both actor-network and activity-theoretic accounts of innovation, allowing their respective dynamics to be explored. Finally, this notion gives a specific and concrete meaning to the commonly-used phrase "more than the sum of the parts" that I have chosen to incorporate in the title of this thesis.

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[219] Tang 1989 (pp. 105-109) describes an early analytic focus on "idea careers" which he abandoned as it became clear that tracking ideas as robust units was problematic. An advantage of the approach I have taken is that it presents no particular problem if options are modified, blended with alternatives or discarded. Productive interaction can be manifest in an increasingly robust network structure of actors aligned with discourse, even if no single proposal survives uniformly intact throughout. Sawyer 2003b (pp. 170-175) similarly brings up difficulties associated with focusing on ideas in conjunction with group creativity. Sawyer's answer to what it is that is created in creative collaboration (in the context of improvisational performance) is the performance itself—including relatively intact sequences that serve as "ready-mades" incorporated in subsequent performances. While Sawyer notes significant differences between performance-based art and collaborative work in organizations, his notion of ready-mades as products of collaboration is compatible with the actor-network concept of punctualisation, or the creation of durable network objects.

Certain criticisms of the approach I have described might nonetheless arise from a canonical ANT perspective. Whereas Latour (2005) admonishes the ANT-analyst to follow controversies, an objection might be raised that my approach overly favours consensus and agreement. I argue that the conception of spatiality I employ, based on a notion of alignment as an interactional "building block" of commitment, is essential to the purposeful nature of small group design activity. The heterogeneous and dynamic nature of actor-networks means, however, that associations always involve translation and that instability, rather than stability, will be the norm. "Design by committee," it seems, is invariably a pejorative term with regard to design, and emphasizing consensus above all else is not a road to success or innovation. As I mentioned above, the method I have described enables more refined questions about potentially constructive aspects of tension and conflict to be answered in further work.

An additional objection may be raised to the network formalization I have adopted. Both Latour (2005) and Law (Law & Hassard 1999) argue against overly static interpretations of spatiality in actor-network accounts.[220] Indeed, Latour (2005) argues for text as the medium best suited for analytic portrayal. I have made a tradeoff here: opting for a more singular conception of spatiality enables an internally consistent representation that is particularly effective at "summing up" analytically-distinct judgements of actors' moves. I justify encompassing my actors in this homogeneous spatial representation by virtue of the fact they share significant common ground[221] and their interaction is sufficiently closely-coupled to ensure that conflicts between viewpoints are reliably surfaced. As I mentioned above, as we depart from these conditions, a singular spatial representation becomes increasingly problematic.

Compared to the heterogeneity present in other actor-network analyses, it may be that the process of translation was less in evidence (compared to those of conscription and punctualisation) in this setting.[222] However, insofar as a collaborative effort involves closely-coupled, face-to-face exchanges with the necessary outcome being some form of consensus and commitment, I believe the network formalization I have described is relevant and potentially useful.

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[220] Latour (in Law & Hassard 1999) particularly objects to the notion of a network that entails an instantaneous, faithful transport and relocation of information which is, in fact, antithetical to the conception of translation in actor-network theory.

[221] This includes respect for the fundamental terms and norms of techno-scientific discourse, (cf. Bucciarelli's (1994) "object world").

[222] Indeed it may be that the problematic communication I identified in Episodes 21 and 54, when experts had difficulty seeing eye to eye and using consistent terms to describe radiation and its effects, exposed a point at which a successful translation (in the ANT sense) had yet to be accomplished.

Implications for Extant Theorizing

The focus of this research has been on the collective accomplishment of design reasoning through interaction; however, the resulting view has specific implications for extant theorizing at more individual and organizational levels. I will touch upon these briefly by returning to the dynamics of generativity and stabilization, discussed above in Chapter 8.

Toward shorter analytic time scales, I have illustrated how connectedness in discourse involved image-schemas—both verbalized and in gesture—that can be incorporated in network structure. Though the mechanisms are probably different, these schemas appear to have played a role in emergent developments arising both in talk and interaction with shared representations. Oxman (2002) asserts that domain-specific knowledge, in addition to more basic perceptual processes, are involved in visually-mediated conceptual emergence at the individual, psychological level. I propose the possibility of extending this view of emergence to include the effects of contributions made *by other participants* in social interaction. Focusing on the schema transformations embodied in participants' contributions may be a way of extending theorizing about perceptual and cognitive emergence to take social interaction into account.

Conceptual blending theory (Fauconnier & Turner 2002) proposes another potential mechanism for generativity, by describing how conceptual blends give rise to mental spaces with emergent properties. We can ask, what mental spaces may be anchored by the features of shared representations? I propose that, based on the interaction I observed, design representations may invoke some or all of the following:

- embodied and kinaesthetic knowledge pertaining to three-dimensional shapes, material properties, movement and other behaviours
- knowledge of abstract principles and mathematical relationships that govern aspects of form and function
- environmental and experiential knowledge about context and the conditions into which the design object will be placed
- process and procedural knowledge of the collective and organizational work required to realize a particular design
- personal experience necessary to estimate the effort required on the part of the individual, along with consequences and benefits likely to result from commitments they make to the team
- awareness of the points at which a successful outcome depends upon the commitments and skills of other members of the team

When someone else reads something unexpected into a representation and voices this to the group, how is one's own interpretation impacted? By looking at the adjacency and content

of contributions, it may be possible to understand in more detail the ways in which these spaces are associated with each other, and how these associations are mediated—both by features of representations and by interaction with other participants.

We can also direct attention to the ways in which representations are implicated in longer-term organizational processes and persistent features of practice. The view I have developed is consistent with the boundary conditions presented by the theoretically-informed ethnographic studies I discussed in Chapter 2. Specifically with regard to collective, organizationally-situated design practice, Henderson (1999) formulated a conception of meta-indexicality as a property of design representations, and articulated a role for prototypes as conscription devices. Meta-indexicality is an unwieldy concept however, perhaps because it encompasses such a great deal.

For Henderson, the concept denotes the drawing together of participants, the holding multiple forms of knowledge (tacit and explicit), as well as an ability to support flexible use in different situations. The framework of situational attributes I have proposed can be used to unpack this property of meta-indexicality to reveal distinct functions, and also to account for the effects of conscription and representations as "carriers of practice" and "social glue" (Henderson 1999). In my view, these functions resolve across the distinct attributes of *responsiveness* (as a matter of co-construction and joint action), *authority* (as a matter of collective reasoning and storytelling), *span* and *robustness* (as matters of continuity with practice). Because each concept is more specific, and because each can be related to distinct actor-network manifestations, the performance of different representations can be understood in terms of distinct features and more meaningfully compared.

Bucciarelli (1994) describes the interactional work of collaborative engineering design as collective "story-making"—the production of a jointly-constructed account with the right kinds of discourse characteristics. I have elaborated this production as a matter of design reasoning, coupled with the alignment of key actors. In essence, by looking at discourse composition, the degree of convergence and closure in an actor-discourse network, we are able to say *when* a good story has been told, *what* it has involved (including how it relies upon any number of technological and representational actors) as well as *who else* considers it to be a good story.[223]

[223] Equally interesting from an actor-network point of view is how the same representation might anchor *different* good stories for different constituencies, by anchoring their respective proximal concerns or otherwise enabling them to accomplish their objectives. Whereas I have provided an account of *conscription* above, this would correspond to the actor-network process of *translation*.

Finally, where Carlile (2002) refers, rather generically, to "knowledge transformation," we can now see a distinct process whereby participants layer their discrete contributions and weave them together, integrating them to create new knowledge and inscribing this in new representations. We can also see how, over time, collaborating participants may need to "un-learn" things they *thought* were essential, as they distance themselves from reasoning, conclusions and representations with which they were once closely aligned.

These theoretical considerations are balanced by a number of more practical implications for collaborating teams and organizational groups. These, and some of the other issues and motivations I identified in Chapter 1, are the subjects to which I return in the following, concluding chapter.