

Can You Accelerate Your Project Using Extreme Collaboration? A Model Based Analysis

John Chachere, John Kunz, and Raymond Levitt
Stanford University

Keywords: collaboration, collocation, latency, organizations, processes

ABSTRACT

This paper sets out our observations, modeling results, and conclusions regarding a novel organizational form applied variously as “Extreme Collaboration” (XC) or “radical collocation.” XC teams are cross-functional, co-located groups enabled with high-performance computer modeling and simulation tools, large interactive graphic displays, a mature shared generic project model that the design team instantiates for the project, and specialized charter, training, support and culture. Our primary data source is the Jet Propulsion Laboratory’s Team-X, which has consistently reduced task durations over many hundreds of projects from original values of 3-9 months down to a few days. Based on our observations, interviews, and surveys of the JPL team, we employ several computational models including the Virtual Design Team (VDT) to illuminate the practice’s basic mechanisms. Key aspects include very short information request-response latency (less than a minute to answer to a question, vs. several days in a traditional team) and a bounded and dedicated knowledge network that provides all the required skills and experience. Our models suggest steps by which designers can re-organize a limited range of projects to reproduce XC and reduce their durations by an order of magnitude. We do not evaluate the impact of this method on the team’s total work volume, cost, or quality. Nevertheless, we conclude that tightening collaboration in ways that are inspired by XC is a strategically powerful tool that is appropriate for most projects.

INTRODUCTION

Extreme Collaboration (XC) is a novel organizational form that has garnered increasing attention in recent days. XC teams are cross-functional, co-located groups enabled with high-performance computer modeling and simulation tools, large interactive graphic displays, a mature shared generic project model that the design team instantiates for the

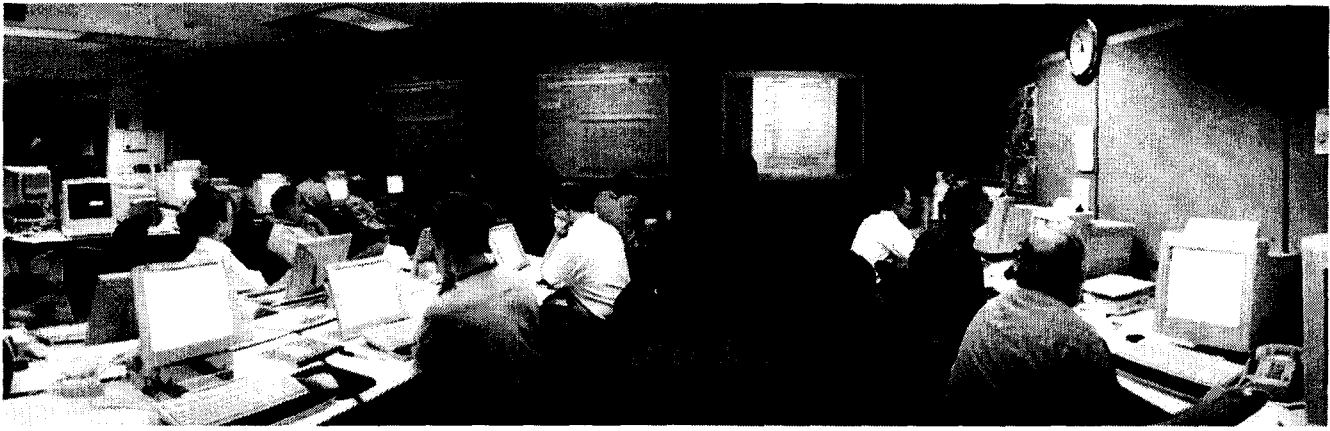
project, and specialized charter, training, support and culture. Some collaborative engineering teams consistently enjoy considerable benefits from the practice, including project schedule reductions of one or two orders of magnitude.

XC is sufficiently new that few (if any) individuals claim an intuition on the system’s behavior and means of success. There is little generally available documentation on the behavior of XC projects [notably Mark 2002, Teasley et al 2000]. In addition, the literature does not comprehensively explain the system’s fundamental mechanisms.

Either to gain competitive advantage or to compete with teams that already employ XC, many organizational designers are tempted to emulate the novel practice with their own teams. Because the method differs from tradition in many ways, it is appropriate for organizational designers to respect the difficulty of reproducing the successful systems’ complex and interdependent organizations, processes, and technical infrastructure. *This paper’s primary focus is the practical organizational designer’s question of how and when XC works.*

Our methodology includes on-site observation, interviews, and surveys. However, our primary contributions result from carefully applying formal models to test the predictions of fundamental (traditional and modern) theories. *A secondary goal of our paper is to illustrate the value of computational organizational modeling in evaluating a domain where intuition breaks down.* By developing each discussion with a computational model, we conserves the systems’ complexities while simultaneously offering a roadmap for many directions of further study. Our models, based on the fundamental theories of traditional organization, suggest new, intuitive theories of XC.

These theoretical results suggest methods by which an important range of applications can adopt XC in its entirety. Of equal importance, they articulate reasons why most organizations may find this move prohibitively challenging in the short term. *Our third and final purpose is to identify*



a metric that can help teams significantly improve their effectiveness in traditional collaboration.

EXTREME COLLABORATION

In hundreds of projects over eight years, the Team-X organization at the Jet Propulsion Laboratory (JPL) has developed and applied XC during their “design sessions”. Figure 1 shows Team-X in a room they have outfitted for XC. Like most Team-X projects, the example project we studied aimed to develop a NASA mission proposal document that conveys an analysis of those designs that Team-X believes can feasibly meet a customer's scientific goals.

The team aimed to complete the design using fewer than five hundred full-time-equivalent hours over a four-week period. In the first, “pre-session” week, certain select engineers pinned down the scientific requirements and mission design with a customer representative. During the second week, the team met for three intensive “design sessions” of XC, each lasting three hours. In the two weeks following the design sessions, the team completed its documentation in a more traditional, distributed fashion.

In practical terms, the design sessions of XC entail the co-location of ten or twenty “station” representatives, each from a different engineering function. These design sessions resemble traditional meetings in that a designated facilitator communicates the agenda and monitors the session's progress. However, in XC the participants continuously form and dissolve “sidebar” conversations to share information or solve emergent problems. Ordinarily, many such conversations are evident through the physical orientation and movement of engineers in the room. Even though the engineers may represent different organizational divisions, there are no managers present in the design session. Instead, the sole facilitator helps sidebars to form, and draws attention to important developments.

The Team-X facilitator monitors the collective design socially and through an information technology infrastructure

that is characteristic of the XC method. Three large screens cover one wall and typically monitor top-level design conformance measures, the mission trajectory, and the designed vehicle's physical configuration. Each domain representative runs a networked spreadsheet model that communicates the design choices currently being considered. The one table without dedicated monitors is typically used by a facilitator, by customer representatives using laptops, and by a speakerphone that connects to remote participants.

We visited JPL's Team-X and ethnographically observed a sample project's three design sessions. In several hours of on-site interviews, we collected quantitative and qualitative details about the participating organization, process, and culture. Finally, after examining this information back at Stanford, we followed up with an online survey covering the amount of time each participant spent in direct work, communication, and rework. While these observations, interviews, and survey provide the foundation of our research, we interpret the data primarily through a set of computational organizational models.

ORGANIZATIONAL MODELING

Both in planning and execution, it is sometimes appropriate to introduce changes to a project based solely on intuition. At other times, it may be more effective to test interventions first in a computational model. This can allow a practitioner rapidly and economically to gauge the interactions between a complex product, organization, and process.

Tracking systems such as Microsoft Project are the most frequently consulted project models, but they are not the most sophisticated. When testing interventions in the Virtual Design Team (VDT) simulator, for example, planners can compare project participants' predicted backlog, coordination effectiveness, schedule risk, and other results between many alternative cases [Kunz et al 1998, ACM; Jin et al 1995, Levitt 1996, Levitt et al, Management Science]. In this way, modelers can plan joint adaptations to

organizations, processes, and culture that will meet a project's goals. In time, our team believes tools like VDT will enable us to engineer projects with a comparable methodology and confidence as is demonstrated on today's automobiles.

In recent years, the computational modeling of organizations has enjoyed a popular resurgence among researchers seeking to better understand new and established theories [March, and Burton, in Lomi and Larsen '01]. By grounding a computational model explicitly in a theoretical framework, researchers can explore complex ramifications of a theory (or set of theories) that extend qualitatively beyond the reach of human intuition. In addition, we have used models to quantitatively predict the effects of theoretical and practical changes in a baseline model. Following the tradition of mathematical proof, when a model of theory produces a recognizable pattern of results, we interpret this and make a new claim. In a perfect world, if the new hypothesis is shown to be false, the model's theoretical premises are disproved (a "proof by contradiction"). At this time, however, model based theory generation is new to domains as complex as project design. In this paper, we apply the technique in its most common modern form- as an engineering method that relies in part on intuition and external observation to validate its claims.

ORGANIZATIONAL THEORY AND PRACTICE

Although it does not tell the whole story, much of mainstream theoretical research on organizations does apply to XC. Thompson [1967] recommends assigning interdependent tasks to teams that are in close organizational proximity. According to this theory, concurrent engineering warrants a flat hierarchy that lowers costs and reduces coordination delays among the many interdependent domains.

As a second example, Galbraith [1977] predicts that when a large number of dependency issues arise, organizations may form temporary, interdisciplinary task forces. We may view the whole of Team-X as one such task force at JPL, while the incessantly forming and dissolving "sidebar" conversations during design sessions serve a parallel function at the temporal and organizational micro-level.

Unfortunately, neither those traditional theories that validly apply to XC, nor the limited literature that is dedicated to the practice, conclusively and concisely explain the effectiveness of XC. Conclusively isolating the set of exact reasons for the effectiveness of XC will require substantial further research.

Fortunately, within limits, an organizational designer may proceed much as engineers do, reaping benefits from the paradigm without regard to the controversy over its most elementary basis. We submit that an organizational designer may productively view XC simply as a purification of the collaborative process- as an absence of unfortunate,

complicating factors. In this view, it offers a standard to compare other projects with, and not vice versa.

COORDINATION LATENCY

Total schedule duration is typically calculated using the critical path method. Perhaps the most common question that is used to determine priorities during project execution is: "Is the task in question on the critical path?" If it is, a given task will receive priority because any delay extends the total schedule duration. Highly optimized schedules, like those of collaborative engineering, often include many parallel tasks that will fall onto the critical path if any substantial delay arises.

Whenever a task lies on the critical path, its requests for information are also on the critical path. The amount of time that elapses between a request for information or action and the satisfaction of that request is termed "coordination latency". Even the best traditional engineering collaboration teams routinely require many hours or even days to service information requests. If each day's labor includes even one request with a substantial latency, the schedules will grow significantly- even though total work volume remains unchanged.

Because XC sessions condense a project timeline by an order of magnitude, the significance of minor delays increases dramatically. A single hour's delay, routine and inconsequential under traditional conditions, can eliminate over one tenth of the Team-X XC period, and waste over a dozen top engineers' time. To be effective, therefore, an XC team must minimize or eliminate all sources of delay- no matter how insignificant they might be under traditional engineering conditions.

RESULTS

We use latency as the theoretical key to understanding the necessary and sufficient conditions for effective XC. However, the conceptual simplicity of latency reduction obscures the complexity and difficulty of its achievement. Just as in battling costs, we find that components of latency come in a multitude of forms, some of which may never be entirely eliminated. Achieving a sufficiently low latency to support XC requires the minimization of every physical, social, and technological coordination barrier.

Table 1 outlines ten of the key latency sources that our study has identified. Organizational designers who seek to improve their coordination effectiveness through latency reduction should realistically assess each of these critical factors. In order for XC to be successful, each of the indicated critical factors must satisfy the corresponding success condition. Aligning a given critical factor will involve an organization-specific technique and difficulty, as the table suggests. We believe that adjusting the critical factors toward success conditions can dramatically improve project schedules, even without engaging in full-blown XC. However, dramatically tightening coordination (through any mechanism) without first assessing and addressing each of

| Critical Factor | Success Condition | Controllability | Failure Modes | References |
|----------------------|--|--|---|-------------------------|
| Structure Dependence | Organization must naturally allocate resources efficiently. | Low- Re-engineer project, organization and process | Unnecessary bottlenecks, idle resources, waiting | IVA |
| Serial Tasks | Tasks are parallel and highly interdependent | Medium- Automate / support decisions, restructure tasks, stagger sessions | Sessions suspended or postponed | CPM |
| Rich Media | Precise, high bandwidth communications (shared databases and displays) | High- Buy/build technologies | Magnified communication errors and overhead | ICEMaker |
| Knowledge Network | Required information must be immediately available. | High- Dedicate / hire experts | Delay for access to external resources | Blanche |
| Flat Hierarchy | No organizational barriers or management overhead | Medium- Empower workers | Decision making slows to a crawl | Thompson |
| Authoritativeness | Actors must command the respect of co-developers | Medium- Staff the confident and competent | Infighting, over-conservatism, defensiveness | |
| Goal Congruence | Participants aspire only to the collective achievement. | Low- Team building, Incentives, indemnification | Inefficient products, infighting, corruption | OrgCon |
| Equivocality | Procedures and goals are well understood | Low- Reduce range of projects | Inaccurate plans, extended debates | B+O |
| Group Communications | Actors must be able to converse in groups of three or more | Medium- Co-locate, buy/build tech | Sub-optimal joint choices, inefficient/ confused processes, failures to commit | Galbraith, Graph Theory |
| Planning | XC operations differ from tradition | High- Provide slack time and resources, introduce gradually | Risk, inefficient / contentious resource allocation, burnout, difficulty keeping schedule | VDT |

Table 1: This table outlines ten obstacles that organizational designers must hurdle in order to effectively employ extreme collaboration. Each factor introduces coordination latency through a distinctive means, and requires unique adaptations.

the critical factors is likely to produce the indicated failure modes.

This paper is too short to fully explain each of the latency sources. We introduce many of them, however, in the following assessments of three crucial elements of extreme collaboration project management.

MANAGEMENT AND STRUCTURE

The hierarchy of authoritative management plays a central role in traditional organizational theory. Because extreme collaboration depends less on this mechanism, understanding the new organizational form requires us to explore new theories. This section explores how the need for management interacts with the processes of extreme collaboration.

Some of the earliest literature on organizations shows that the activities of multiple managers creates delays through the divergence of priorities and processes. Thompson and Galbraith indicate that trying to avoid this with a multi-layer hierarchy would impose routing delays. Because none of these phenomena is acceptable at the speed of a full-blown extreme collaboration, we argue based on

theory that XC requires a relatively flat management hierarchy.

At the same time, it is only possible for one manager to supervise eighteen engineers with a light hand. Our observations conform to this analysis, in that a single facilitator- supported by a display of Team-X's collective results- routinely leaves participants free to embark upon processes of their own choice. Again, we argue based on theory and observation that the feasibility of extreme collaboration for a given project depends on its ability to operate efficiently with minimal managerial intervention.

Interaction Value Analysis (IVA) uses mathematical queuing theory to demonstrate that imposing structure-through management, for example- only improves upon long-term, naturally emergent organizational behavior under precise circumstances [Nasrallah et al 2003]. They show that some projects are unlikely ever to develop efficient (globally optimal) operations without sustained management intervention. Others are likely, in time, to naturally achieve a perfectly efficient equilibrium (in which Pareto optimality equals global optimality).

| Project Factor | Target | Factor Definition |
|-----------------|------------|---|
| Diversity | High | The number of independent skill types possessed by parties in the network |
| Interdependence | Low | The degree to which parties with distinct skills need to collaborate in order for their individual tasks to be of value to the organization |
| Differentiation | Low | The contrast in skill levels between the most skilled and the least skilled parties for a given skill type |
| Urgency | Low | The rate at which pending work becomes useless if not completed |
| Load | Medium-Low | The demand for work relative to resources |

Table 2: Reproduced from Nasrallah, Levitt, and Glynn '03. The mathematical Interaction Value Analysis model indicates that structure adds little value to a project when any of the factors listed achieves the value in the second column. As an example, JPL's Team-X gains little long-term value from rigid organizational structure because its diversity is high- each participant represents a unique discipline. XC cannot accommodate projects that require a substantial amount of structure.

Setting realistic expectations and budgeting for XC's learning curve can provide enough time for IVA's long-term results to apply. However, the criteria that IVA identifies may involve substantial adjustments that are specific to an application. According to IVA, an extreme collaboration project should satisfy one of the criteria that Nasrallah et al identify, and that we reproduce in Table 2. If the project can be shaped to meet *just one* of the criteria, it will develop efficient operations in the long term. If the project can meet none of the criteria, substantial inefficiencies will result, and the management style exemplified at Team-X will prove insufficient. Our analysis suggests that under these latter conditions, the project is not amenable to extreme collaboration.

MANAGEMENT AND DECISION MAKING

The mere knowledge that management will make few of an organization's decisions does not enable us to plan all that is necessary for a shift to extreme collaboration. Our study investigates the detailed matter of *how* XC organizations differ from traditional ones using Virtual Design Team (VDT) simulations.

Academics and professionals have calibrated the VDT model with experience from a wide range of project studies, and have used it to make some strikingly accurate predictions. The system predicts project performance, however, based on the assumption that workers route substantial decisions *only* through the management hierarchy. We may thus interpret the simulator's findings as representative of the predictions that an expert in traditional project planning might offer.

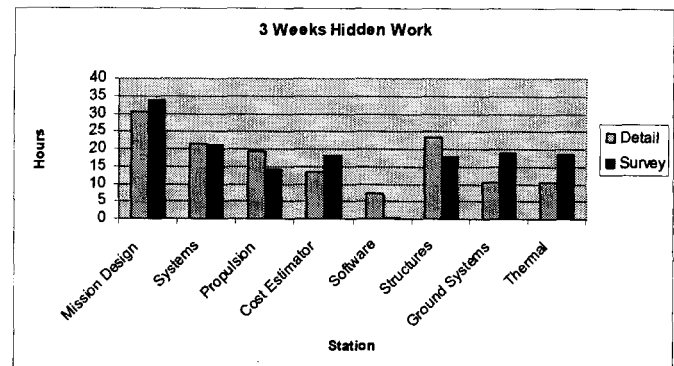
As technology accelerates it becomes less common for technical workers' supervisors to possess the specialized knowledge that subordinates require to perform their duties.

The manager's centrality is limited, in that problems are frequently directed elsewhere, through a network of technically knowledgeable experts. Over its long development, Team-X has adapted to distribute its total exception-handling load effectively among the specialist participants. Therefore, we assume that their reported work volumes fairly represent actual XC demands.

Comparing the VDT simulation results with those reported by Team-X, we measured the differences between operations under the authority hierarchy and knowledge network paradigms. Technically, we modeled the XC project with engineers assigned to individual tasks, with the same direct work volumes predicted by Team-X participants. We then calibrated the simulator and retrospectively predicted approximately the same total coordination volume reported by Team-X participants.

This experiment produced two significant results. The first was a simulator prediction that engineers waste approximately ten percent of their time waiting for management decisions. True, even in extreme collaboration, management plays an indispensable role on matters of project goals and top level planning. However, at JPL we observed virtually no project delays that were accountable to a management bottleneck. This outcome dramatically illustrates the inadequacy of traditional authority hierarchy theory. In fact, we suggest that the result *quantifies* in approximate terms our allegation that planners – including human ones – who depend on traditional intuition to design a decentralized, collaborative engineering structure (like XC) are likely to overestimate the importance of management direction. The ten percent figure also suggests an amount of acceleration that a project might experience simply from going from a bottlenecked management hierarchy to a more efficient knowledge network.

Our second result is that while VDT can be



retrospectively calibrated to show the same total coordination volume reported by Team-X participants, we found that the distribution among individual tasks was not a perfect match (Figure 4). We believe this results from the simulator's inability to model the routing of decisions through the knowledge network of participants. Based on this result, we alert organizational designers to the danger of underestimating the workload that technical experts will incur as they coordinate heavily in decentralized knowledge-based projects such as XC.

MANAGEMENT AND KNOWLEDGE

Our team initiated this project with the understanding that exceptions often flow along knowledge network lines. Our work supports this modern hypothesis but also substantially extends it. Our observations suggest that organizations such as XC are already designed and/or evolved in counterintuitive ways to leverage and indeed to control the knowledge network itself.

More specifically, every member of Team-X uses a spreadsheet that his or her organization has established explicitly for the task. The system requires the engineer and spreadsheet to encapsulate much of the data and procedural knowledge that is required during design sessions. Further, while most organizations occasionally leverage outside resources' technical capabilities, XC requires that the team of engineers collectively possesses all of the technical expertise that may be called upon during the design session.

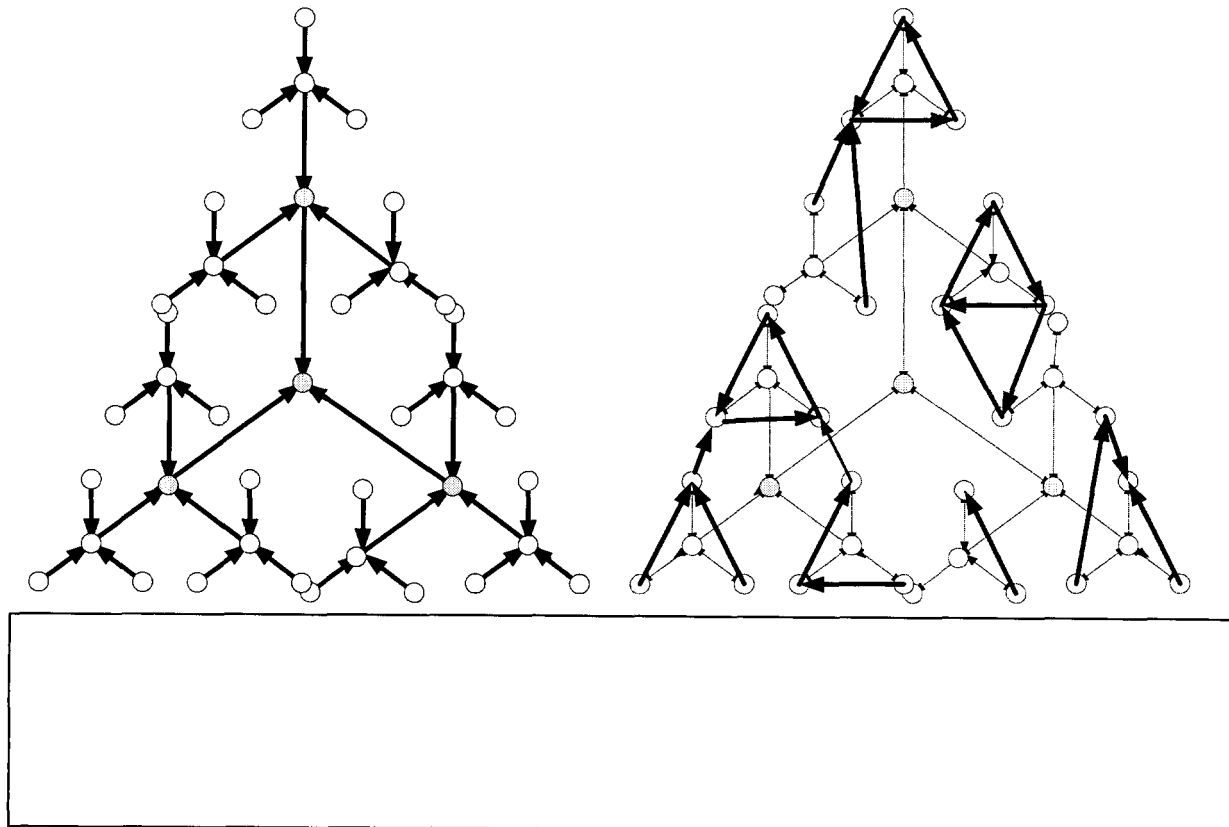
In terms of theory, the XC team uses a closed and available knowledge network.

Team-X's adaptation contrasts starkly with the alternative. If an XC session requires knowledge that lies outside the ken of its participants, the team has to access outside resources, and this will introduce substantial latency. Because of the high task interdependence, one such instance could render worthless a sizable fraction of the available design session time.

The "sidebars" observed at Team-X solve a major coordination problem that emerges when a large number of dependencies stretch across the knowledge network. In mathematical terms, "hierarchy" describes a directed, acyclic graph structure, also known as a "tree". The illuminating word here is *acyclic* (lacking cycles). Under a simple model of decision making and information exchange a hierarchy may be guaranteed to effectively distribute authority and reliably terminate- albeit at a sometimes suboptimal solution. However, where cycles arise among *dyadic* (two-person) relations, termination at any solution cannot be guaranteed. This phenomenon may be the basis for numerous project delays in collaborative engineering where response latencies can have non-trivial durations.

DISCUSSION

Team-X solves this problem in XC by enabling *all* members of a decision-making cycle to virtually pool information, values and alternatives. Mathematically, this



process may be viewed as virtually collapsing a cyclic subgraph (or one containing cycles in large cases) into a special "sidebar node". One implication of this theory is that XC requires a culture that promotes egalitarian and respectful collaboration and technical conflict resolution.

DISCUSSION

XC is analogous to the operation of high-performance automobiles in that many elements of the total system must be designed for specialized behavior. Bumps in the road, hardly noticeable at twenty miles per hour, can be disastrous at two hundred. Therefore, well before a race, the track must be inspected and smoothed, and this is the function of Team-X's week long "pre-session" study of the project at hand. Similarly, just as every engine component is specialized and inspected, every station's home organization painstakingly prepares its product model and participating representative. Finally, once the race is on, there is no time for ambivalence. An XC team, like a driver, must be prepared to make decisions quickly and conclusively. While the appearance and behavior that result from these adaptations is radically different on the surface, the fundamental forces and operations in play remain the same. Even at high speed (low latency), we are still looking at a car, and we can understand it by extending the fundamentals.

The complexities of extreme collaboration merit a healthy respect. In technical terms, extreme collaboration is a chaotic system that may behave quite differently under only slightly differing conditions. We advise organizational designers to adopt the practice gradually and warily until the effectiveness of XC becomes more thoroughly understood.

Within the context of this caution, we have also sought to convey our optimism that the intuitive theories that explain XC apply quite broadly. Of particular interest to practitioners, this implies that we may learn much about XC simply by carefully applying established theories to the new domain. Theorists may find equally provocative the inverse conjecture that new theories uncovered by observations of XC might illuminate broad fields that have stagnated from a lack of profoundly distinct data points.

Clearly, much remains to be said about the design of extreme collaboration. Each of the latency sources in Figure 1, for example, merits an exposition of considerable depth. Nevertheless, we believe our example analyses to conclusively impart several important points.

In particular, we hope to have drawn attention to and shed light upon two fundamental elements of modern organizational behavior. The first, coordination latency, indicates that all organizations are located on a quantifiable continuum of collaborative efficiency. We suggest that every organization can benefit from an audit of individual latency sources.

The second major theoretical concept, knowledge based exception handling, alerts practitioners to the steady increase in dependence on experts in the technical labor force.

Organizational designers cannot afford to continue discounting this phenomenon or addressing it with short-term solutions. Today's knowledge bottlenecks may have similar impacts to yesterday's management bottlenecks, but they also herald an entirely new set of opportunities.

As a final, practical matter, we have illustrated the power of computational organizational models to both extend and lend specificity to qualitative theory, ethnography, and survey research. Properly applied, the methodology can enhance practical organizational design just as effectively as it strengthens scholarly results [Kunz et al '98]. The recent expansions of particularly compatible social science and computational theories are creating an exciting time for practitioners of this research method [March, and Burton, in Lomi and Larsen 2001].

ACKNOWLEDGMENTS

The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. We are grateful to NASA ARC's Engineering for Complex Systems Program for supporting the work under Grant Number NCC21388, and for providing valuable feedback. We are especially indebted to the Jet Propulsion Laboratory's Team-X, including Rebecca Wheeler, Robert Oberto, Ted Sweetser, and Jason Andringa.

We conducted our analysis in the rich contexts of Stanford University's Virtual Design Team group and the Center for Integrated Facility Engineering.

BIBLIOGRAPHY

- > Galbraith, J. R. (1977), *Organization Design*. Reading, MA: Addison-Wesley.
- > Jin, Y.; R. Levitt; T. Christiansen; J. Kunz. 1995. "The Virtual Design Team: Modeling Organizational Behavior of Concurrent Design Teams," *International Journal of Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, Vol.9, No.2, (April) 145-158.
- > Kunz, J.; T. Christiansen; G. Cohen; Y. Jin; R. Levitt. 1998. "The Virtual Design Team: A Computational Simulation Model of Project Organizations," *Communications of the Association for Computing Machinery*, (November) pp.84-92.
- > Lomi, A. and E. Larsen, 2001. *Dynamics of Organizations*, AAAI and MIT Press
- > Mark, G., 2002. "Extreme Collaboration" *Communications of the ACM*, Volume 45, Number 6 (June), pp. 89-93.
- > Nasrallah, W.; R. Levitt, P. Glynn. 2003. "Interaction Value Analysis: When Structured Communication Benefits Organizations" *Organization Science* forthcoming in 2003
- > Levitt, R. 1996. "Organizational Analysis and Design Tools: State of the Art," *First International Conference on Computational and Mathematical Organization Theory*, Monterrey, Mexico (October)
- > Teasley, S., Covi, L., Krishnan, M., Olson, J. 2000. "How Does Collocation Help a Team Succeed?" *Association for Computing Machinery Conference on Computer Supported Cooperative Work*.
- > Thompson, J. D., 1967. *Organizations in Action: Social Science Bases in Administrative Theory*, McGraw-Hill, New York