Agent Interactions in Construct:
An Empirical Validation using Calibrated Grounding

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ABSTRACT: *We conducted a validation study for Construct, a multi-agent network model of socio-cultural co-evolution. Our particular focus is on the ability of Construct to produce an initial state of agent interactions which have reasonable equivalence to the communication network of a real-world organization. We used the calibrated grounding technique to perform the validation. Results of the study show that Construct can produce a valid state of initial interactions. In addition, we were able to gain some insight into the nature of the organization.*

1. Introduction

Computational models are intended to represent real-world systems of behavior (Law & Kelton, 2000; Turnley, 1995). We often use a computational approach as a way to represent the complexities that contribute to system functioning (Carley & Gasser, 1999). These complexities are often not amenable to analytic reduction (Lee, Schreiber, & Carley, forthcoming). Computational models provide a means to various useful ends such as normative analysis, predictive emulation and theory development (Burton, 2003).

But this approach also brings up the issue of validation. The validation process determines the level of equivalence between the real-world system and the model (Balci, 1998). We need validation in order to build credibility for the model and have confidence in the ends that are obtained. In addition, the validation process can provide other benefits such as phenomenal understanding, application guidance and future research directions.

We performed an external validation of the computational model Construct. Construct is a multi-agent network model of socio-cultural co-evolution. Our particular goal is to validate the ability of Construct to represent the person-to-person communication network of a small organization. We used the calibrated grounding technique to perform the validation. This process also provided some phenomenal understanding by allowing us to draw some insights about the drivers of communication for this particular organization.

The paper is organized as follows. First, we describe Construct and the part of the model which is the focus of this validation. Then we discuss the methodological approach. This section includes a description of the dataset and an explanation of the calibrated grounding technique. Lastly, we present and discuss the results.

2. Construct

Construct is a multi-agent network model of socio-cultural co-evolution (Carley, 1990; Schreiber, Singh, & Carley, 2004). Construct agents perform an action cycle each timeperiod. This action cycle is the basis of the socio-cultural co-evolution. In an action cycle, the agents first choose interaction partners. Then, they communicate and learn knowledge. They subsequently change their beliefs based upon their updated knowledge. Lastly, the agents perform tasks and make decisions using their current knowledge. Outcome measures that are collected include performance accuracy, consensus and knowledge diffusion.

The outcome measures depend upon agent interactions as agent interactions prominently figure into agent learning. Therefore, the first step in validating Construct is to test the degree of equivalence between agent interactions and real-world communication networks. If the interactions of Construct agents reasonably represent the organizational communication network then we can have enough confidence to suggest that outcomes from the model could reasonable reflect outcomes of the real-world system.

There are two core variables that determine agent interactions in Construct. These two variables are organizational representation and interaction process. Organizational representations are network characterizations of the organization. There were two network representations collected in the dataset used for this study: knowledge network and task network. These networks are of interest because it is assumed that they influence organizational communications. In other words, the people in the organization will communicate with each other based upon their task assignments and their possession of knowledge.

The task network is a reflection of 'who does what' and is based on the tasks that people are assigned. The task network is represented as matrix. Figure 1, presents an example of a task network. A 1 reflects the assignment of a task to an agent.

	Task			
Agent	1	1	1	1
	0	1	1	1
	0	1	1	1
	0	0	0	1

Figure 1: Example task network

The knowledge network is a reflection of 'who knows what'. Knowledge categories that are relevant to the context are defined as the 'what'. For example, the context of the organization used in this study was software engineering context. Knowledge categories included are object-oriented programming expertise, web development expertise, interface design expertise and project management expertise. The knowledge network is the level of expertise that each person possesses within each category. Figure 2 presents an example of a knowledge network. A 1 reflects that the agent has the expertise.

	Knowledge			
Agent	1	1	1	0
	0	1	0	1
	1	1	1	1
	0	0	1	0

Figure 2: Example knowledge network

There are two basic interaction processes in Construct: relative similarity and relative expertise. They are based upon well-known human interaction processes. Homophily (Lazarsfeld & Merton, 1978) forms the basis of relative similarity. Homophily is the tendency of similar people to interact with each other. For example, those of the same age or in the same field of work tend to interact. Communicative ease, trust, comfort and access are arguments supporting homophily based interaction.

An example in Construct would be the following. Agents acting with relative similarity will tend to interact more with those who have similar tasks than those who have dissimilar tasks. In the model, this tendency is calculated as a probability of interaction among agent pairs. The probability that agent i and j will interact based on relative similarity is calculated by the following equation. This is computed for every pair of agents.

$$\mathbf{RS_{ij}} = \frac{\sum_{k=0}^{K} (S_{ik} * S_{jk})}{\sum_{j=0}^{I} \sum_{k=0}^{K} (S_{ik} * S_{jk})}$$

Expertise seeking (Cross, Rice, & Parker, 2001) forms the basis of relative expertise. Expertise seeking is interaction based on the search for knowledge. For example, people who are in need of specialized task knowledge will seek out others who have it. Knowledge integration and a need for novel or specialized knowledge are arguments supporting expertise seeking.

An example in Construct is the following. Agents who are acting with relative expertise are inclined to look for and interact with those who possess diverse knowledge rather than those who possess overlapping knowledge as compared to the ego agent. Like relative similarity, the relative expertise tendency is reflected in the modal as a probability of interaction among agent pairs. The probability that agent i and j will interact based on relative expertise is calculated by the following equation. This is computed for every pair of agents.

$$\mathbf{RE_{ij}} = \frac{\sum_{k=0}^{K} (X_{jk})}{\sum_{j=0}^{I} \sum_{k=0}^{K} (X_{jk})}$$

Figure 3 shows an example of a probability of interaction matrix. The probabilities between agent pairs are non-symmetric because of the relative asymmetries. In other words, communication can be initiated from one pairwise direction more often than another.

	Agent			
Agent	.00	.12	.04	.05
	.08	.00	.05	.04
	.01	.03	.00	.11
	.10	.01	.07	.00

Figure 3: Example probability of interaction matrix

3. Method

3.1 Datasets

We tested Construct using a dataset collected from a software development company[1]. This data was collected by an outside source and we had no direct contact with the company. The organization consisted of 16 people. The task and knowledge networks were collected on this organization and were used as input into Construct. The task network consisted of 24 task nodes. Therefore, the task network was 16 people by 24 tasks. The knowledge network consisted of 19 knowledge categories. Therefore, the knowledge network was 16 people by 19 knowledge categories.

In addition, the communication network was collected and used to validate the agent interactions in Construct. The communication networks are similar in format to the task and knowledge networks. Figure 4 shows an example communication network. The values correspond to communication frequency. A higher value reflects an increase in communication frequency.

	Person			
Person	0	1	1	1
	1	0	0	1
	1	1	0	1
	1	0	1	0

Figure 4: Example communication network

3.2 Calibrated Grounding

We use calibrated grounding to test the validity of the Construct agent interactions. This technique combines the approaches of initialization grounding and internal calibration. Figure 2 shows an overview of the calibrated ground technique.

Initialization grounding is the use of empirical data as initial input into the model. This grounds the model with a representation of the real-world organization. Two different organizational representations were used in this study, task network and knowledge network. Internal calibration, as used in this study, is the selection of an organizational representation and an interaction process. Two distinct interaction processes are used in this study, relative similarity and relative expertise. Agent interactions are calibrated by calculating the probabilities of interaction using one of the interaction process equations on one of the organizational representations.

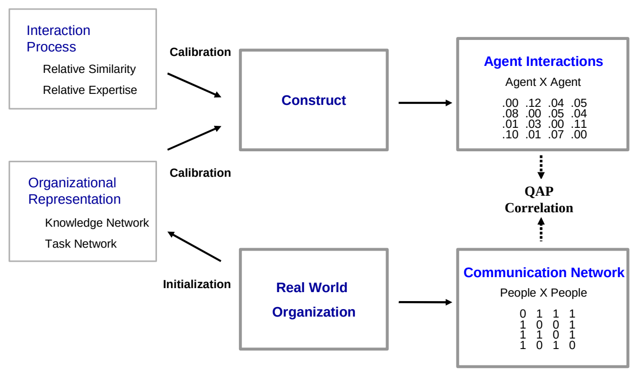

Figure 2: The calibrated grounding technique

The focus of this study is on a valid state of initial agent interactions. The probabilities of interaction are not averaged over timeperiods. Also, there were not any stochastic processes from Construct involved in computing the probabilities for this particular study. Additionally, there were not any adjustments made to the internal mechanisms of Construct in order to fit the model to the data.

We define reasonable equivalence as a significant correlation between the initial state of agent interactions and the real-world network. Correlation is tested using the Quadratic Assignment Procedure (QAP). QAP uses a non-parametric permutation test to determine significance. This procedure is used because relational data violate the assumption of independence and traditional parametric methods are inappropriate.

The following describes the functioning of QAP. First, the corresponding cells of the agent interaction matrix and the real-world communication matrix are compared. This results in a Pearson correlation coefficient value. Then corresponding rows and columns of one matrix are randomly permuted and the correlation coefficient is recalculated. In other words, if rows 1 and 3 are permuted then so are columns 1 and 3. This maintains the dependency that exists among the relationships in the

[1] The software company dataset courtesy of Ashworth (2006).

matrix. The permutation step is repeated thousands of times which results in a distribution of correlation coefficients. In our study, the permutation step was run 2,500 times.

Significant correlation is determined by the placement of the original, non-permuted coefficient within the overall distribution. We tested for significance at the standard 0.05 level. The QAP test was run for every organizational representation and interaction process combination.

We need to note that the correlation coefficient cannot be interpreted to indicate a degree of correlation. In this regard QAP is non-linear. For example, a higher correlation coefficient does not necessarily mean that it is stronger. We are only interpreting significance by the correlation passing the test at the 0.05 level. But we can interpret significance levels greater than 0.05 as being stronger results.

3.3 Subject-Matter Expert Verification

We conducted an additional step in verifying the results and interpretations of this study. We showed the results and our interpretations to a subject-matter expert who had knowledge of this specific organization. We asked this expert to provide their opinion.

4. Results and Discussion

Table 1 presents the QAP correlation results. The task network and relative expertise settings produced valid agent interactions. This gives credibility to the model and provides confidence that model outcomes could reasonably reflect real-world outcomes.

		Organizational Representation	
		Knowledge Network	Task Network
Interaction Process	Relative Similarity	0.059	0.179
	Relative Expertise	0.023	0.141*

Table 1: QAP Pearson correlation coefficients
** - 0.05 level of significance*

These results also provide us with some phenomenal understanding. First, only the task network organizational representation validated. What this suggests is that the task structure of the organization is the predominant driver of communication. Second, the relative expertise interaction process validated when using the task network representation. This suggests that there are high interdependencies among the tasks. The agents were seeking to interact with others who had different tasks than their own. The interpretation that these task interdependencies are high is supported by the result of only relative expertise validating.

As an additional validation step, we asked a subject-matter expert whether these validation results and phenomenal interpretations made sense. This person had first-hand knowledge of this particular organization. The subject-matter expert verified that the quantitative results and interpretations made perfect sense for this organization and its context.

5. Conclusion

This validation study provided credibility to the Construct model. We can now start a simulation with an agent interaction pattern that reasonably matches the real-world organization. This provides confidence in running what-if analyses and projecting outcomes.

We also gained phenomenal understanding of the organization through this analysis. Task-driven communications and high task interdependencies describe the nature of this organization. Although this information can be garnered through other means - such observation, interviews, etc. - we were able to draw these conclusions at a distance and without having direct contact with the organization.

There are several future research directions for validating Construct. First, Construct should be validated using data representing various organizational sizes and contexts. It may be the case that Construct is better suited for representing certain types of organizations. We need to understand how robust the model in order to apply it appropriately.

Second, Construct should be validated using various organizational representations. There are other representations that may influence communications. For instance, cognitive networks represent people perceptions. People will interact and make decisions based on their perceptions. How well does Construct validate using various organizational representations? Are certain representations more robust in validating across various group sizes and contexts? Answers to these questions may help focus future data collection efforts and provide a general understanding of organizational communications.

Third, predictive results verification is needed. This should be done for outcome measures as well as network change. Validation of outcome measures would require running Construct overtime and comparing the model output to real-world outcomes. This comparison can be accomplished through a variety of statistical regression and correlation techniques.

Validation of network change also requires the running of Construct overtime but instead compares changes in agent interactions to longitudinal datasets of the communication network. This comparison can be made using QAP as described in this paper.

The concurrent validation of outcome measures and network change would be the most stringent test. There is a potential for deriving considerable gains in terms of phenomenal understanding and theory production in performing a validation of this sort. It also would establish Construct as a fully applied model.

As a final note, any model validation is a matter of degree (Law et al., 2000), including the one in this paper. There is no objective proof, only confidence in a reasonable representation of the phenomenon (Forrester, 1961).

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