# *Lifting the Veil: Drawing insights about design teams from a cognitively-inspired computational model*

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*Novel design methodologies are often evaluated through studies involving human designers, but such studies can incur a high personnel cost. It can also be difficult to isolate the effects of specific team or individual characteristics. This work introduces the Cognitively-Inspired Simulated Annealing Teams (CISAT) modeling framework, a platform for efficiently simulating and analyzing human design teams. The framework models a number of empirically demonstrated cognitive phenomena, thus balancing simplicity and direct applicability. This paper discusses the model's composition, and demonstrates its utility through simulating human design teams in a cognitive study. Simulation results are compared directly to the results from human designers. The CISAT model is also used to identify the most beneficial characteristics in the cognitive study.*


*Keywords: computational model, design cognition, teamwork, engineering design*

Much cognitive research in engineering design has focused on individuals, despite the fact that most engineering design is actually performed by teams (Paulus, Dzindolet, & Kohn, 2011). This work focuses on developing a better understanding of team-based design through computationally simulating the team design process. Empirical studies are a common means for exploring design cognition and for testing new design methodologies. However, these studies can incur a high personnel cost while only returning a limited amount of data. It can also be difficult to isolate the effects of specific characteristics. This work introduces a computational framework that simulates team-based engineering design through creating software agents that directly solve engineering problems. In addition to offering a resource efficient test bed for evaluating design strategies, this framework can be used to test the conclusions from cognitive studies. It can be used to peel apart aspects of human design, and provides a succinct representation of designer behavior. The purpose of the framework is not

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to replace cognitive studies, but rather to augment traditional methods of investigation, accelerating the discovery of improved design methodologies.

A significant amount of work has attempted to simulate the performance of both teams and individuals (Fan & Yen, 2004). For instance, both the Virtual Design Team model, and another model applied to teams at NASA's Jet Propulsion Laboratory, incorporated detailed descriptions of design team organization and interaction (Jin & Levit, 1996; Olson, Cagan, & Kotovsky, 2009). Both models were used to simulate complex design tasks, but were also burdened by high model complexity. For instance, the model by Olson et al. (2009) used approximately 1000 distinct variables, and required nearly 100 000 lines of code for implementation. Still other work has utilized agent-based models to explore the formation of mental models during team problem-solving with respect to both interaction structure (Dionne, Sayama, Hao, & James, 2010) and agent memory (Sayama, Farrell, & Dionne, 2011). Mental models were created by either adding noise to the true problem function, or interpolating between known function values. That work obtained results that agreed qualitatively with the literature, but only explored one- and two-dimensional continuous problem domains, and was not compared to the results of any human studies. A recent agent-based design team model also explored the effect of team structure and task complexity on the formation of transactive memory (Singh, Dong, & Gero, 2012, 2013). That work also obtained results that agreed qualitatively with the literature, but modeled the design problem as an abstract task network instead of directly solving a concrete design problem. Other work simulated with great detail the tasks involved in an integrated product development team, but did not apply the model to a real design task, or offer empirical validation (Crowder, Robinson, Hughes, & Sim, 2012).

Regarding the simulation of individuals, simulated annealing (Kirkpatrick, Gelatt, & Vecchi, 1983), a stochastic optimization algorithm, has been used as an effective model for the efforts of individual human problem-solvers (Cagan & Kotovsky, 1997). More recent work has demonstrated the potential benefit of using computational agents to rapidly test and refine rule-based search strategies that can then be provided to human designers (Egan, Cagan, Schunn, & Leduc, 2014). The rule-based search strategies included both stochastic and univariate approaches. In that work, both computational agents and human participants solved a continuous domain problem with a small number of variables, but the work was not extended to more complex problems.

When humans solve a problem, they tend to learn strategies that can be expressed in terms of the move operators that apply to the problem (Langley, 1985; Newell & Simon, 1972). Solution strategies can also be expressed in