Abstract of Research Interests Related to

Design from Physical Principles

James R. Rinderle

Mechanical Engineering Department
Carnegie Mellon University
Pittsburgh, Pennsylvania 15213
(412) 268-3677
rinderle@cmu.edu

Designing is a process of making decisions which fix the configuration of a product or process. Design decisions are not, however, independent of each other. Rather, they are coupled as a consequence of physical interactions among components and because of the absence of a close correspondence between functions and single components. Although physical modeling is commonly employed in engineering to predict product performance, physical characteristics can also be used to direct the generation of design alternatives and to facilitate the understanding of fundamental design tradeoffs.

Various means for generating valid configurations of components, including grammatical generation and other transformational mechanisms, generally reflect only some of the required physical characteristics of a product. Furthermore, they produce valid configurations without distinguishing *preferable* configurations. We employ physical principles to select valid configurations which are preferable as a consequence of the physical characteristics of the product. In the simple domain of mechanical transmissions, for example, we select transformations which allocate reductions or which result in common power paths or structures to reduce component count and to achieve compactness.

The relations between component form and behavior are a direct consequence of fundamental physics. These relations are well known in many cases, however, in many others the component level form-behavior relations are not known *a priori* and depend on the context in which the component is used. The relationship between motor torque and weight, for example, depends on other design constraints. By first combining and then abstracting, for example, the fundamental magnetic, electrical and mechanical principles involved in electric motors it is possible for the designer to come to understand and utilize the implications of physical principles on the component level behavior when designing systems comprised of such components.

Unfortunately, device behavior cannot be obtained simply by aggregating the behaviors of the constituent components and full simulation is intractable and hard to use in a design scenario. Fortunately, in most useful mechanical devices, kinematic constraints eliminate many degrees of freedom and eliminate the need to consider some physical phenomena, for example, rotational motion. We have developed a modular physical modeling framework in which pre-defined components can be assembled to automatically formulate a dynamic model of a device. We have also developed a suite of mathematically sound reasoning techniques which make it possible to eliminate irrelevant physical relations and to explicate dominant device level characteristics.

These approaches, combined with a variety of mathematical constraint reasoning and constraint dominance techniques analogous to typical engineering design reasoning, greatly mitigate the complexity inherent in mechanical design and facilitate the focused generation and reticulation of mechanical designs. More complete descriptions of these approaches can be found in the publications listed below.

S.E. Sarma and J.R. Rinderle, "Interval Propagation: Theory and Methodology," *Proceedings of the Fourth ASME Design Theory and Methodology Conference*, Arizona, Sept., 1992.

W. Tidd, J.R. Rinderle and A. Witkin, "Design Refinement via Interactive Manipulation of Design Parameters and Behaviors," *Proceedings of the Fourth ASME Design Theory and Methodology Conference*, Arizona, Sept., 1992.

S.P. Hoover, J.R. Rinderle, S. Finger, "Models and Abstractions in Mechanical Design," *Design Studies*, Vol. 12, No. 4, Oct. 1991.

J.D. Watton and J.R. Rinderle, "Identifying Reformulations of Mechanical Parametric Design Constraints," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, Vol. 5, No. 3, 1991.

J.R. Rinderle and L. Balasubramaniam, "Automated Bond Graph Modeling and Simplification to Support Design," *Journal of Dynamic Systems Measurement and Control*, (in review), 1991. (Also in *Automated Modeling 1991*, DSC Vol. 34, WAM, Atlanta, December 1991.

E.R. Colburn and J.R. Rinderle, "Design Relations," *Proceedings of the Second ASME Design Theory and Methodology Conference*, Chicago, September 1990.

J.R. Rinderle and V. Krishnan, "Constraint Reasoning in Concurrent Design," *Proceedings of the Second ASME Design Theory and Methodology Conference*, Chicago, September 1990.

S.P. Hoover and J.R. Rinderle, "A Synthesis Strategy for Mechanical Devices," *Research in Engineering Design*, Vol. 1, No. 2, 1989.

S. Finger and J.R. Rinderle, "Transforming Behavioral and Physical Representations of Mechanical Designs," *First International Workshop on Formal Methods in Engineering Design, Manufacturing, and Assembly*, Colorado Springs, CO, January 1990. (Available from the Engineering Design Research Center at Carnegie Mellon University as Technical Report EDRC-24-35-90)

J.R. Rinderle, "Function and Form Relationships: A Basis for Preliminary Design," NSF Workshop on the Design Process, Oakland, CA, February, 1987. (EDRC-24-05-87)