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BENCHMARKING JOHN VON NEUMANN'S INFORMED SELF-REPLICATION ARCHITECTURES FOR IN SITU PRODUCTION IN SPACE ENVIRONMENTS

Abstract

A mission-critical driver of humanity's space exploration endeavor is the timely establishment of in situ self-containing resilience, since providing redundancy and logistics of spare parts and consumables come with all kinds of cost, likelihood to failure, and are constrained by the laws of physics. Closed-loop approaches are significant in maintaining self-containing resilience for specific space environmental cases like spacecrafts and stations. Still, they require machines for recycling and re-building items which come with energetic and economic costs, attrition, and error-proneness. Although additive manufacturing with 3D-Printing as its most prominent prospect could be a candidate for in situ production since it consists of mechanical parts, the problems mentioned earlier remain. One way to approach the problems is to integrate the production apparatus into the to-produced product. Inspired by nature, John von Neumann famously developed and called this concept Universal Constructor, commonly known as self-replication machine. We discuss how this approach unlocks a variety of advantages. The ontogenetic growth reduces the energetic and economic costs of the production of an incremental unit. It scales, reduces costs of transportation by use of self-replicating seed payloads, and can be used for self-reparation or self-replicating in case of malfunction. Recent advances in interdisciplinary research areas comprising synthetic biology, chemical computing, and soft living matter give rise to a variety of viable alternatives building on von Neumann's universal constructor. This survey aims to characterize existing theorized and practical concepts associated with von Neumann's self-replication architecture and benchmark them against the state-of-the-art in-space industrial manufacturing methods. We identify and categorize the underlying core architectures of various self-replication concepts and approximate, discuss and interpret for typical space exploration use cases the minimal thermodynamic costs, energy consumption, production time, external energy supply requirements and constraints of building an incremental unit while operating in different space environments. We conclude that the fitness of self-replication architectures vary depending on the applied use cases and space environments. Our survey can be used to indicate the proper concept according to the mission requirements.