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Self-awareness in agile assembly systems

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Assembly systems consisting of self-aware robotic modules react to incoming production orders by combining their services.

Tomorrow's manufacturing systems will need to be highly responsive and agile to cope with increasingly dynamic production conditions caused by frequent changes in product requirements, low production volumes and design flexibility. Awareness is growing among suppliers that industrial systems must be quickly reconfigurable, take a plug-and-play approach to avoid time-consuming and labour-intensive reprogramming and be resistant to perturbation.

Evolvable assembly systems (EASs)[1] offer one such solution. Based on a shop-floor control approach known as CoBASA,[2] an EAS consists of robotic modules that can be combined in many different ways to provide various functionalities. Agentified EAS modules (i.e., associated with a software agent) carry local intelligence and self-knowledge thanks to tiny controllers and unifying software wrappers. Each module is capable of simple skills and spontaneously engages in coalitions with other modules to provide composite skills. Product orders are also represented by agents that bring generic assembly plans, describing which parts need to be assembled in which way.

EASs ease the task of reconfiguring an existing system or building new assembly systems whenever a new product order arrives. However, the initial configuring of the modules, positioning them into an appropriate assembly system layout, monitoring their positioning, adapting to production conditions and reconfiguring in case of failure are still done manually. To overcome this limitation, we are adding self-organization to EASs. The agents will be able to spontaneously assemble to create shop-floor layouts and transform generic assembly plans into layout-specific assembly instructions that precisely define the executable movements of each module.

To introduce self-organization, we augmented CoBASA with MetaSelf,[3] an architecture for self-organization and self-adaptation. MetaSelf exploits policies (such as "Never exceed the maximum speed") and metadata (such as "Gripper A had maintenance treatment one week ago") to monitor and guide the system towards user-specified goals. Policies guide the automatic

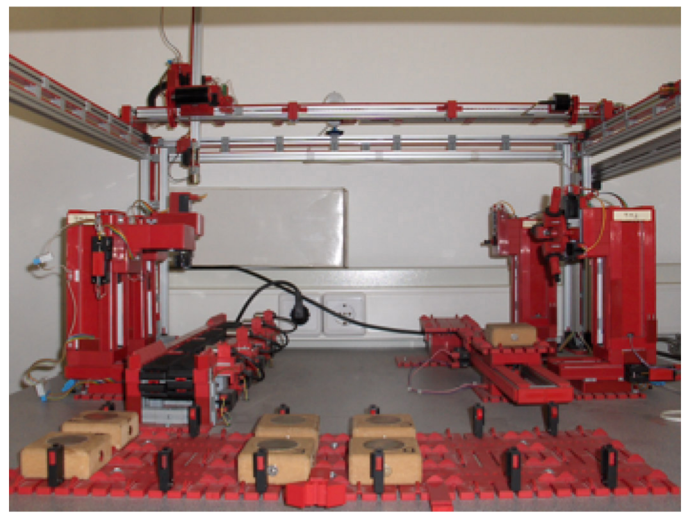

Figure 1. Educational shop floor. The wooden blocks in the front are the symbolic products being handled and treated by the system. On the left and right are robots that execute operations on the products. The construction at the top is a pick-and-&place crane that transports the products between the storage area and the robots.

shop-floor layout formation at *creation time* as well as system operation at *production time*. At creation time, the modules select the partners they need to fulfil the requested tasks, and at production time they monitor themselves and their neighbours. Figure 1 shows an educational shop-floor model used to illustrate case studies and initial experiments with self-organization. Figure 2 shows real EAS modules (grippers and axes) grasping and moving marbles.

To date, the results of our efforts in this area include the design[4,5] and architecture[6] of self-organizing EASs,[7,8] as well as development of a specific ontology (i.e., conceptual hierarchy) and 'on-the-fly' creation of coalitions.[9] For example, if axis A is combined with axis B and gripper C, they form a coalition to collaborate and execute the task at hand (most likely a pick-and-&place job). Formal specifications describing self-organizing EASs are executed in Maude[10]—a language and tool based on rewriting logic that models the chemical abstract

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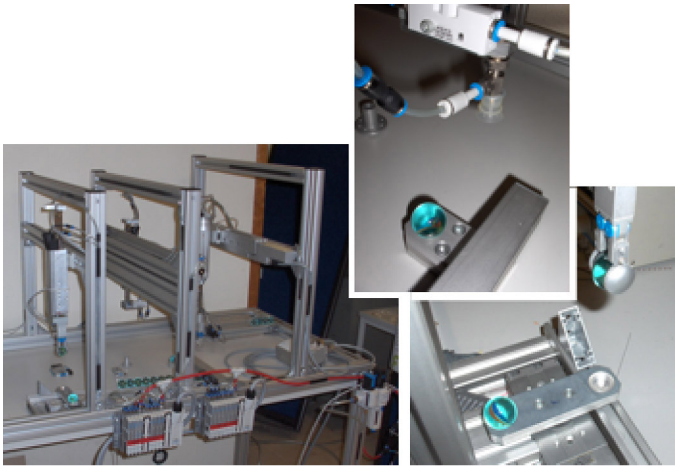

Figure 2. Evolvable assembly system modules. Left: The entire system, composed of linear robotic axes, both horizontal and vertical. Middle: A suction gripper that is about to grip a marble (our symbolic product to be handled). Right: A two-finger gripper holding a marble on top of a feeder device that transports the marbles into the work space of the gripper.

machine[11]—and act as a proof that the self-organization mechanism is able to find a suitable solution for a set of robotic modules and a generic assembly plan. That is, it is able to create a suitable layout and derive the layout-specific assembly instructions. An introduction to this technique, as well as as preliminary results, are presented elsewhere.[12]

Practically speaking, the user would define preferences and constraints for the layout to be created. In our test case, the layout has a serpentine structure and the feeders are always placed on the left side of the robot. The rewriting process then derives the layout-specific assembly instructions, again following changeable rules for how robot movements must be executed. For the test case, we focused on simplified pick-and-place operations in a point-to-point trajectory. Thanks to the robots being aware of their neighbours both on a logical level as well as through distance sensors, collisions are avoided.

In summary, we have created concepts for EASs to self-organize and self-adapt in response to changing requirements and to cope with failures.[13] The robotic modules the systems comprise are *self-aware*: they know their skills, their physical characteristics, their interfaces and whom they can collaborate with to form composite skills. These are then offered in response to tasks that need to be performed to assemble the desired product. A layout is formed according to user-defined rules, and the layout-specific assembly instructions are derived.

The next steps in Maude will relate to the inclusion of different rules for layout creation as well as experimentation with assembly plans for different products, requiring different assembly movements. Furthermore, the implementation of these concepts in a real system would be desirable but depend on the availability of funding.

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