3 MAKING A PERFECT 'GIN AND TONIC': MASS-CUSTOMISATION USING HOLONS

Martyn Fletcher
Agent Oriented Software Limited,
Institute for Manufacturing, Mill Lane, Cambridge CB2 1RX, UK.
Email: martyn.fletcher@agent-software.co.uk

Michal PĚCHOUČEK
Department of Cybernetics, Faculty of Electrical Engineering, Czech Technical University in Prague, Karlovo Namestri 13, 121 35 Prague 2, CZECH REPUBLIC.
Email: pechouc@labe.felk.cvut.cz

The paper presents a model of mass-customisation in manufacturing based on designing and deploying intelligent software agents. We illustrate how this mass-customisation would work in a novel scenario – making a perfect 'Gin and Tonic'. We also discuss some of the benefits this balanced approach can offer businesses in terms of pragmatic holonic software engineering within complex environments and a formal representation of holon operations to academia.

1. INTRODUCTION

The emergence of consumers needing specialised products and services tailored to their particular requirements has resulted in manufacturing companies having to exert greater control over how their product families are configured, presented and delivered. We focus on a particular domain of such personalisation of products, namely *mass-customisation* because it highlights the facilities needed by a manufacturing business to re-organise its shop-floor and supply chain. In the context of this paper, mass-customisation is the customisation and personalisation of manufactured products and services for individual customers at a mass production price. Currently available models for customising how a product can be configured and its presentation altered focus on ensuring that artefacts are manufactured with sufficient generality in a single organization and rely on a central configuration station (often manual) at the end of the production line that can refine the product appropriately. Yet this approach is not true mass-customisation as the factory still produces batches of products that are to be sold to specific retail outlets, which are then beholden to undertake focussed marketing efforts to sell the goods.

A finer-grain mass-customisation model will enable an individual person to issue a unique configuration, possibly via the Internet, of how they want their product to look and feel. Furthermore they do not want to wait long lead times for delivery. This type of mass-customisation is finding its way into factories of various manufacturing domains, such as the envisaged 5-day car or the responsive packing of personal grooming products. In both these environments, the customer selects how they want their intended purchase to be configured, for example in the case of a car purchase system, a user might specify "I want a car with a 3.2 litre engine, 6-speed manual gearbox, painted midnight blue and with a particular style of CD player installed". A key point concerning these existing models for mass-customisation is that they focus on the assembly of sub-components and that the user only has the capability to select which component they wish installed into their product. In this paper we propose a model of mass-customisation that offers the customer the capability to decide how a product is made based on the combination of non-discrete sub-components that can be assembled to meet the user's unique needs. An industrial example where such customisation would be of significant benefit is the process industry. Here batches of chemicals are combined and processed in specific ways to make a final chemical that suits the needs of the customer who placed the order.

Within the scope of this paper, we choose a more light-hearted case study, namely a small-scale manufacturing and robotic system that could be built into a 'themed' pub or cocktail bar. This system lets the customer select how they want a 'Gin and Tonic' drink be made for their personal taste. The drink is assembled with the customer selecting the type of glass, the volume of ice, the volume of Gin (of which they may be several varieties to choose from), and the proportion of Tonic water to be added. The finished drink would then be delivered to their table using a shuttle-based transportation system – ready for the person to enjoy!

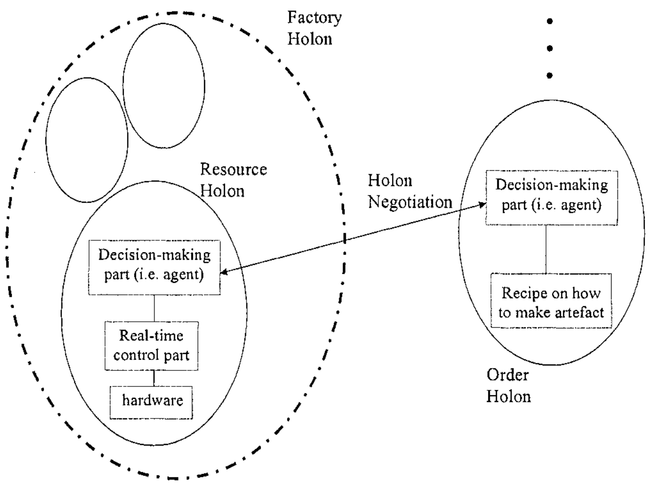

Figure 1 – Control of a Holonic System with Intelligent Software Agents

The technology we intend to use to construct the control system for this 'Gin and Tonic' maker is a new generation of Intelligent Manufacturing Systems (IMS) called *holonics*. Holonics uses intelligent software agents (Figure 1) to control how distributed and real-time processes are executed and coordinated. We will use the SMART formal framework for Agency and Autonomy of (Luck and d'Inverno, 2003) to design and deploy our agent-based holons. The paper is structured as follows. In section 2, we review relevant literature on holonic manufacturing for mass-customisation. Section 3 presents our case study for using mass-customisation, namely the perfect 'Gin and Tonic' maker environment. Section 4 presents a model of the holonic system to control the 'Gin and Tonic' maker. This model is based of the SMART approach for designing holons and their interactions in terms of intelligent software agents. Some conclusions are presented in section 5.

2. LITERATURE REVIEW

In traditional manufacturing environments (both at the internal factory level and at the entire supply chain management level), having customisation of product families and making low cost goods has been considered to be mutually exclusive. Mass production provides low cost artefacts but at the expense of uniformity. As (Davis, 1996) highlights, customisation of products was in only the realm of designers and craftsman. The expense generally made it the preserve of the rich. For example if you wanted a suit of clothes made, then you can either have an 'off the peg' suit but if you want clothes that are made to your specific body measurements and made from the desired material then you need a skilled tailor who is often rather costly. Today, new interactive technologies like the Internet, allow customers and retailers to interact with a manufacturing company to specify their unique requirements that are then to be manufactured by automated and robotic systems.

To clarify by an example, existing car assembly plants usually build batches of the same car, leave them on the car lot and try to sell them by aggressive marketing. In a factory geared to mass-customisation of discrete part assembly, people would select the exact specifications of their product, e.g. a car in terms of all configurable options (paint colour, leather seats etc). Then the entire production line, containing a variety of entities (e.g. assembly cells, inspection stations, automated guided vehicles and so on) would reconfigure themselves to build this specific product. The car can then be delivered to the person in a few days of asking. This reconfiguration of machines, re-planning, re-scheduling and handling faults are very difficult to achieve in current factories even if they are geared towards simple forms of 'option-based' mass-customisation. Examples of mass-customisation in the beverage industry are very limited: it is usually the case that the brewers decide how a mixed drink should look and then market this style. For instance Smirnoff mixes a given amount of vodka with a fixed volume of citrus juice and markets it under the name Smirnoff Ice™. Yet everyone is different and so someone might want a different mix of vodka and juice, which is rather difficult for large-scale brewers to make. Such mass-customisation must also operate within the scope of 21st century factories (or pubs) where customisation can occur not just at the assembly stage but also throughout the entire manufacturing process.

Holonic manufacturing systems are a particular variety of IMS based on the ideas of (Koestler, 1967) that many natural and man-made organisations are more flexible to changes when they are inhabited by stable intermediately entities. In a production context, these entities (called holons) need to act autonomously and cooperatively to ensure the overall organisation is more robust, responsive and efficient than today's manufacturing systems can offer. HMSs are recursive in their construction, with each holon having the option to contain sub-holons and combining real-time control with artificial intelligence to manage low-volume high-variety manufacturing processes. Also FIPA has provided templates for how agents should communicate and how multi-agent systems should be managed. A significant part of their standards effort has related to using the "Belief, Desire, Intention" (BDI) model of rational agents. Beliefs model the world state and are obtained from continuous, imprecise and incomplete perceptions. As the agent's specific purposes may change over time, it needs to know its own objectives and desires. When trying to achieve these goals, the agent must create a sequence of actions that cannot be changed as often as the environment changes. Thus the overall system needs to be committed (i.e. have an intention) to execute a certain sequence.

However it should be noted this architecture has received little attention in industry and is yet to prove itself in real-world HMS scenarios where mass-customisation demands that high quality user interfaces, system agility and robustness are paramount (Mařik, Fletcher and Pěchouček, 2002).

3. THE PERFECT 'GIN AND TONIC'

This section describes our case study of how holonic mass-customisation will operate in terms of a manufacturing environment to make and deliver a perfect 'Gin and Tonic' for each customer in a bar. The physical environment is characterised by:

- Customers sit on bar stools next to drinking stations on the bar. Each station has a touch-sensitive screen displaying an Internet web-page so that consumers can specify how their drink should be made (e.g. set relative proportions of Gin).
- At the drinking station, there is also a Radio Frequency Identification (RFID) reader that can read the identity of a tag embedded in the glass the consumer is drinking from. The station also has a sensor to detect how full the glass is, in order to make recommendations about when to purchase another drink.
- A MonTrack™ conveyor system runs the length of the bar upon which independent shuttles move along. These shuttles carry the consumer's drink through using a flexible fixture that can adapt to the size and shape of the glass being transported. A shuttle can stop at either of the two drink assembly cells in order that the drink can be made, or at any drinking station so that the appropriate customer can take their drink. Only when the glass reaches the consumer who ordered the drink will the glass be released. The shuttle can determine that it is at the correct drinking station because it also carries a RFID reader and stops when it reads a tagged glass that the customer is currently using. This means that a customer can move freely between drinking stations (say because a pretty girl at the other end of the bar invites him for a chat).
- There are two drink assembly cells, each with a docking station to firmly hold the shuttle. The first is dedicated to selecting the correct glass type from storage and placing ice into the glass. The cell can also pour any measure of two different types of Gin into the glass. The second cell has access to the same two bottles of Gin (which are located on a turntable) and can also pour from three bottles of specialist Gin. Only cell 2 can add Tonic water into the glass.

- To achieve this functionality, each cell has an anthropomorphic robot (possibly a Fanuc M6i) with a flexible end-effecter that can pick up and pour either the Gin or the Tonic water out of the correct bottles. Each bottle has a RFID tag on it and the end-effecter has a reader so the bottles can be placed anywhere inside the robot's working envelope and it can still determine the correct bottle.

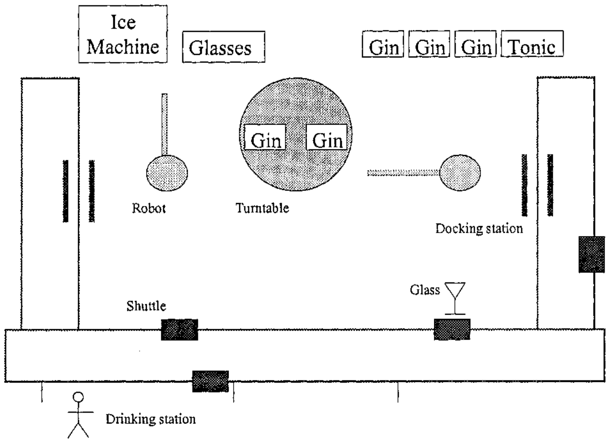

Figure 2 – Schematic Layout of Physical Environment

The layout of the perfect 'Gin and Tonic' environment is shown in Figure 2. The operations by the system for mass-customisation are:

- The consumer sits at a drinking station and specifies the configuration of their drink. If they are very thirsty then they may wish to indicate that they want the drink quickly and are willing to pay some more money for the privilege of speedy delivery. This amount of money is used by the holons in their negotiations and will be deducted from the consumer's credit card when the drink arrives. Agreeing the amount of money to be spent is needed because the consumer is not getting a 'standard' measure of Gin but rather the precise number of millilitres that he/she wants.
- An order holon (modelled using a software agent) is created to ensure that the drink is made correctly and delivered to the customer on time and to budget.
- The order holon interacts with the necessary resource holons in the system (also modelled as agents) to satisfy the goals within the recipe associated with making the drink. The generic recipe for making a perfect 'Gin and Tonic' is: (i) reserve the services of a shuttle to transport the drink around the system, (ii) select the correct type of glass and put it on top of the shuttle, (iii) add the correct volume of ice into the glass, (iv) add the correct type and volume of one or more Gins, and (v) add the correct amount of Tonic water.
- The drink is then delivered to correct drinking station where the customer is now sitting (maybe different from where he/she placed the order) using the RFID tags on the customer's glass for recognition.
- The information, in a local XML database, associated with the unique RFID tag attached to the glass is updated to reflect how the drink has been made and to

whom it belongs. Using this information, customer profiles can be created to better market the drinks and also to aid the bar's replenishment of used bottles.
- If the sensor at a drinking station determines that a drink is nearly finished then the customer is offered another drink (possibly at a promotional price).

We now demonstrate that the SMART (d'Inverno and Luck, 2001) approach can bring significant benefits to our modelling of the agent-based holons and their interactions in controlling the perfect 'Gin and Tonic' making environment.

4. SMART

4.1 Overview of SMART

The richness of the agent metaphor has lead to many different uses of the term and has caused a situation where there is no commonly accepted notion of what constitutes an agent. In response, Luck and d'Inverno have developed the SMART agent framework to unambiguously and precisely provide meanings for common agent concepts and terms. SMART enables alternative models of particular classes of agent-based system to be described, and provides a foundation for subsequent development of increasingly more refined agent-oriented concepts, such as holonics. The SMART approach does not exclude (through rigid definition) any particular class of agent. Rather it provides a means to relate different classes of components within an agent-oriented system, e.g. the holonic control system for our 'Gin and Tonic' making environment. The SMART process is as follows. Initially, the software designer must describe the physical environment and then, through increasingly detailed description, define the software components within the control system to manage this environment. These components are arranged into a four-tiered hierarchy comprising entities, objects, agents and autonomous agents (agents that established their own goals through motivations). These classes constitute SMART's view of the world. For our purposes, the aim of the SMART approach is to construct a formal framework for the components in the holonic control system and their interactions, using formal notation such as Z, which is independent of the agent architecture used to implement these agent-based holons. For an introduction to the Z formalism, readers are referred to www.zuser.org/z/

4.2 Designing Holons using SMART

As stated above, the SMART framework reflects the complex view of the world held by an agent-founded control system in terms of components of varying degrees of functionality. To formally model these components, a language like Z can be used so each component is represented as a schema and is included by other components. In Luck and d'Inverno's model, there are separate schemas for action, perception and state for each of the four component layers. In our refined model, we add a fifth layer to the component hierarchy, namely that of a holon because a holon refines the functionality of an autonomous agent in order to be cooperative and recursive. Hence there are Z schemas to represent *HolonAction*, *HolonPerception* and *HolonState* as shown in Figure 3. We refer interested readers to (Luck and d'Inverno, 2003) for a full description of how component schemas are defined. We focus on the new schemas using that style.

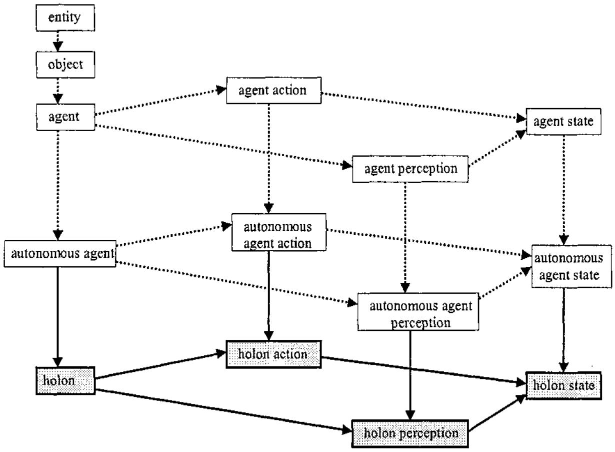

Figure 3 – Z Schemas in a Formal Framework for Modelling Holons

4.2.1 Holon Specification

We begin our specification of holons by introducing *roles*.

Definition: A role is a distinct entity, which contains a description of the relationship, and facilities that the participants in a team/sub-team (or holon / subordinate holon) relationship must provide. The role relationship is expressed in terms of the motivations and belief exchanges implied by the relationship. A role will lead to the autonomous generation of motivations by the holon and will impact the holon's behaviour and reasoning in order to address these motivations.

Like the other Z aspects of the formal model, the type of the role is described using a given set, [Role] as follows. The rows show how holons build upon the schemas of autonomous agents, agents, objects and entities. We have included columns for the order holon and a robot holon (an essential resource holon).

Schema	**Variable**	**Order**	**Robot**
holon	roles	{order management}	{material handling}
autonomous agent	motivations	{achievement, delivery}	{achievement, utilisation}
agent	goals	{acquire shuttle, get glass, get ice, get Gin, get Tonic}	{load glass, insert ice, poor Gin, poor Tonic}
object	capabilities	{interact with resources, use recipe}	{lift glass, hold bottle}
entity	attributes	{glass type, Gin volume, ice volume, Tonic volume}	{yellow, stationary, heavy}

A holon can now be defined.

Definition: A holon is an autonomous agent with a non-empty set of roles. It is specified simply as:

```
Holon
  Autonomous Agent
  role : P  Role
  ----------
  role != {}
```

Where P is the Z syntax for a power set containing, in this case, the roles that any holon might perform. To illustrate these principles, consider a shuttle carrying a drink: the shuttle cannot be considered a holon because, while it may have the ability to determine its own motivations (such as wanting to take the optimal route or wanting to go to a repair in case of damage), it does not have the ability to define how its motivations fit into the roles of the overall system. In this respect, it relies on other holons (i.e. a Track Manager holon) for purposeful existence. However the robot is a holon because it has the need to be recursive and cooperative through a role, and has the ability to generate internal goals in order to satisfy a role. Suppose a role for the robot is material handling. In normal operations, the robot will generate motivations (and in turn create internal goals) for achievement (related to making drinks in the bar) and utilisation (related to ensuring it is working to maximise its throughput). These motivations can be decomposed, recursively, to motivations for each of six independently controlled joints/axes that give the robot its degrees or freedom, and these must be coordinated to make the drink. The robot will create motivations for its joints to make the requested drinks, but if it recognises that the schedule of operations is not optimal then it will generate the utilisation motivation to determine a better sequence of work. It could also recognise that if works for some long duration on a certain type of task then its performance could degrade and so it abandon this achievement motivation and generate a new motivation to compensate for this reduced performance. Such a robot is a holon because its motivations are not imposed, but are generated dynamically in response to its environment and roles.

4.2.2 Holon Perception, Action and State

Goals, motivations and roles are relevant to determining what a holon perceives in the environment, which can be independent of its roles etc. Therefore the schema below specifies a holon's perception as a modified version of what the underlying autonomous agent perceives schema to reflect these extensions. A holon will also have some mechanisms to determine its actions and behaviour with respect to the environment and its roles.

```
— HolonPerception ————————————————————
Holon
AutonomousAgentPerception
holonperceives : P  Role -> P  Motivation -> P  Goal -> Env -> View
————
dom holonperceives = {roles}
—————————————————————————————
```

The action selection functions of a holon is a refinement of the AutonomousAgentAction scheme of an autonomous agent and one is produced every time a role is used to transfer knowledge (messages) among holons. The state of a holon is defined in terms of the state of an autonomous agent. Changes to this state are as a result of its roles, motivations, goals, perceptions and the environment. For brevity we have not included the HolonAction and HolonState schemes, we just point out that they have a similar structure (with addition of roles) to the schemes AutonomousAgentAction and AutonomousAgentState respectively. Finally we specify how a holon performs its next set of actions as a refinement of the

AutonomousAgentInteracts schema. These extensions to the agent hierarchy help us to formally define and describe how holons act autonomously, cooperatively and recursively in an unambiguous manner.

4.3 Applying the Formalism

Again consider our 'Gin and Tonic' environment. An order holon has a role that demands it gains the services of the resource holons (including the robot) and within which, the order holon has a motivation to make a drink for a consumer that satisfies his/her taste and incurs minimal cost. Meanwhile the robot has a role of making drinks and, within the scope of that role, has a motivation to produce as many drinks as possible per hour. Hence an *interaction* to achieve cooperative scheduling is needed to resolve this potential motivational conflict. An interaction is composed of two motivations and an interaction content that is designed to migrate the two holons from original states in their respective motivations to a pair of destination states. Therefore a dynamic holarchy (in other words a temporary coalition among holons with some prescribed organisation) is composed of a set of holons' motivations and their interactions. All interactions must only take places between two holons' motivations belonging to the same holarchy. Within the scope of such an interaction, the process may follow any style of agent-oriented collaboration metaphors, such as the phases of the classic Contract Net Protocol. From this starting point, we can observe that the Z formalism applied by the order holon during the Announcement phase of its MakeMeDrink motivation (interacting with the Robot holon's PourDrink motivation) is as shown below.

```
── Holon Interaction, Type: Contract Net ──────────
Holon: Robot; Motivation: PourDrink && Holon: Order; Motivation: MakeMeDrink
   ── Phase1: Announce ──────────────
      ── Drink Specification ──────────
      Gin Type #1: 22 mili-litres
      Gin Type #2: 7 mili-litres
      Tonic: 73 mili-litres
      Ice: true
      Glass Type: tumbler
      ── Customer ──────────
      Person Identity: Joe Bloggs
      Last Drink RFID Tag: 024530032180036282002730
      Cost and Deadline: £1.73 @ Tuesday 9 December 2003, 12:45
   ──────────
      ── Process ──────────
      for each Robot
        (request(:sender (:name Order) :receiver (set (:name Robot)))
        :content ((action (:name Robot) (pour_drink(drink_specification,customer))))
        :protocol fipa-call_for_proposal :language FIPA-SL :conversation-id order123)
```

We can now exert balance and look at the case for pragmatic businesses to adopt the holonic vision. Merits of this agent-based holonic approach to mass-customisation include the opportunity for global optimisation of the customisation processes within the manufacturing business could be accomplished through this model. There are multiple criteria upon which a factory configuration can be judged and so optimised upon. For example, minimizing mean delivery time of a certain class of specially parts, maximizing the number of competing cells that can supply a part (i.e. giving alternatives if one cell cannot provide the requisite part), and minimizing the volume of parts stored. The agent-based holons provide means for such multi-criteria optimisation via mediation and so forth within their interactions Fault-tolerance and reliability are two criteria essential for any pragmatic mass-customisation. The dynamic agility that the holons' intelligent software agents have provides a solid foundation for the development of robust supply chains with supplier enterprises that can offer customised goods quickly to meet customer-specific orders. Moreover, by having holons use decentralised control, the system as a whole displays graceful degradation in the face of hardware failures, rather than complete collapse. This means that the time to deliver a customised product is kept short to maintain customer satisfaction. We now make some concluding statements.

5. CONCLUDING REMARKS

We have outlined the key features of a 'continuous' mass-customisation model for manufacturing using the holonic approach. The design and deployment of these holons is based on applying the SMART framework to build holons using intelligent software agents. We have also discussed several issues associated with how some typical holons will operate in a novel mass-customisation environment that makes a 'Gin and Tonic' to satisfy customers' unique requirements for their perfectly-combined drink. As businesses increasingly shift their emphasis towards high-variety low-volume production to meet the ever-changing demands of people for customized goods, management of the businesses resources via agent-based holons with distributed control are the logical consequence. Clearly there is incentive for businesses to introduce holonic and mass-customisation ideas onto their shop-floors, supply chains, and even into the odd pub, in order to meet the ever-growing demand for customised products. Moreover competition between businesses to manufacture such customized goods cost-effectively, balanced with the academic value provided from a formal Z-based framework, will make the arrival of holonics imminent. Future research will focus on evaluating the model, i.e. how scaleable it is.

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