Emergent e-Logistics Infrastructure for Timely Emergency Response Management by Collaborative Problem-Solving with Optimized Resource (Re)Allocation

Mihaela Ulieru
Electrical and Computer
Engineering Department
The University of Calgary
Calgary, T2N 1N4, Alberta

ulieru@ucalgary.ca

Rainer Unland
Institute for Computer Science and
Busines Information Systems (ICB)
University of Duisburg-Essen
45117 Essen, Germany

Unlandr@cs.uni-essen.de

ABSTRACT

This paper presents first results for a theoretical foundation for emergency e-Logistics based on an extended FIPA-compliant layered multi-agent system architecture. The approach is based on the holonic paradigm proposed by A. Koestler in his attempt to create a model for self-organization in biological systems and proven by the HMS Consortium to be very useful for resource management and allocation in the manufacturing domain. We integrate the mechanism of emergence into the holonic paradigm encompassing both vertical and horizontal integration of resources in a distributed organization to enable the dynamic creation, refinement and optimization of flexible ad-hoc infrastructures for emergency e-logistics management.

General Terms

Algorithms, Management, Design, Reliability

Keywords

Emergency response management, emergent virtual organization, dynamic cyber infrastructure, self-organizing distributed systems, multi-agent systems

1. Introduction and Project Objectives

This work originates in our previous results targeting the development of enabling information infrastructures for global production integration obtained working with the Holonic Manufacturing Systems (HMS) Consortium in the past seven years [22][39][29][24]. In particular, within the Holonic Enterprise Project [38] joining international research and industrial forces in a unified effort to develop integration FIPA-compliant standards for global collaborative enterprises, our contribution of Test Bed "FIPA-Enabled Supply Chain Management" [32][31][30][23] of a 1-Tier collaborative agents architecture for customer-centric global supply chain. This is currently being extended to the implementation and standardization of Holonic Enterprises [33][36]. Recently a theoretical model inducing *emergence* in holonic virtual organizations has been developed [35][37], which expands previous results in the modeling of multi-agent systems dynamics [29][26][28] with a mechanism of evolutionary search in Cyberspace [27].

The *overall objective* of this project is a theoretical foundation and the definition of *standards for emergency e-Logistics based on an extended FIPA-compliant layered multi-agent system architecture*. We target automated mechanisms for ad-hoc creation of collaborative organizational structures endowed with highly efficient and cost-effective resource allocation and management for disaster relief, medical or military emergency applications, capable to constantly optimize and adapt their structure and behavior according to new/emerging needs. Addressing and handling management mechanisms for emergency logistics is a natural development following our existing results in the field of holonic agency. Such a mechanism would ensure as well customer-centric logistics management in manufacturing supply chain management and other application areas. We aim to expand the emergence model presented in [35] to a layered (3-tier) holonic architecture, thus building a cross-level (vertical integration)/cross-organizational (horizontal integration) coordination backbone for fast reactivity, dynamicity, and flexibility.

In the next section we will discuss state-of-the-art in e-logistics infrastructures. Section 3 introduces our emergent e-Logistics infrastructure model. It is based on a layered multi-agent system architecture. We will especially discuss two important issues, namely, how cross-enterprise services can be discovered and selected (section 3.4) and how agents can be flexibly equipped with different kinds of goals that allow them to react in different ways to different requirements (section 3.5). In section (section 3.2 an example scenario is introduced which provides the context for the discussion of the above issues. Finally, section 4 concludes the paper.

2. State-of-the-Art in the Development of e-Logistics Infrastructures Supporting Emergency Response Management

In today's dramatic context lessons learned in other areas are transferred and adapted to leverage the quick development of response mechanisms to emergency situations [18]. Private sector 'best practices', in particular techniques inherited from enterprise logistics and supply chain management, are considered especially useful in addressing emergency preparedness planning and defense logistics as well as post-incident analysis and reporting [4].

Major Research Consortia, such as the EU (IST-1999-21000) MobiCom recently calibrated their purpose to respond to the new demands with adequate technologies [8]. The e-Motion project of the MobiCom Consortium aims to enhance citizen safety and se-

curity by proving the interoperability of diverse wireless technologies and their mutual support for a better response to emergency cases through three trial set-ups: Emergency Management, Tele-ambulance, and Transport Surveillance [6]. Although they provide a first big step towards emergency response handling by ensuring the seamless integration of devices/units/entities involved (Fig. 1, from [6]), the second big step - development of collaborative coordination infrastructures enabling (vertical and horizontal) workflow management in virtual organizations [33], has not yet been considered in the deployment of emergency logistics operations. Rather a flat approach ensuring peer-to-peer communication of organizations and devices is taken [6]. This approach characterizes as well most literature related to virtual organizations creation, where coalition formation [16] addresses mostly the horizontal integration of several organizations through various brokerage mechanisms ([11][14]).
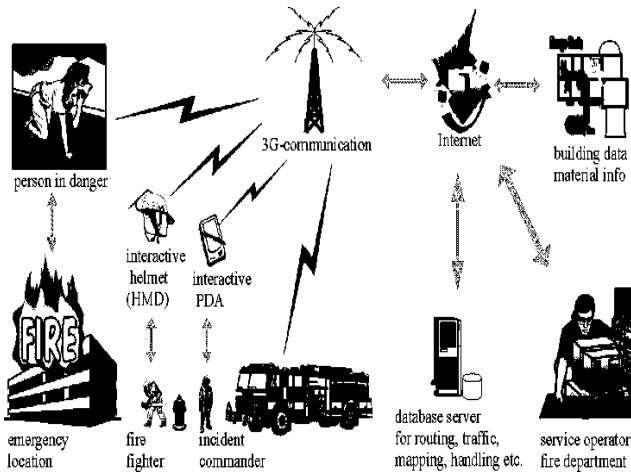

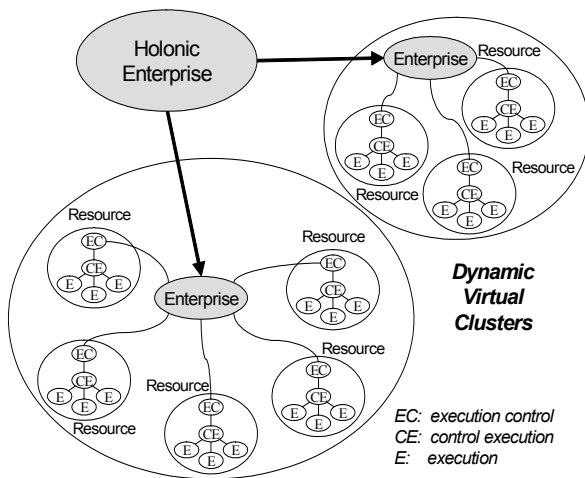**Fig. 1:   A scenario in emergency logistics**

EC: execution control
CE: control execution
E: execution

Fig. 2:   Holonic Enterprise

More advanced approaches to virtual organization integration [21] propose a 3-tier cross-organizational workflow model that captures private partner workflows, workflow-views and coalition workflows. By this they overcome the limitations of the 1-tier peer-to-peer [11] or 2-tier private-public models [9]. Although such architectures respond to the needs of dynamic 'on-the-fly'

resource allocation (enabling the self-organization) they are limited (as well as the other models [11][9][14][16]) to a predefined/static structure of a virtual organization with fixed/known partners and resources. State-of-the-art in 'key-to-glass' [1] service discovery and composition [3][19] are not exploited to create, refine and optimize ad-hoc context based [43] and purpose-driven dynamic organizational structures – the most challenging requirement in emergency logistics management [41].

To date techniques for on-demand user needs [7] using nested interchangeable views suggest that nested hierarchies (holarchies [37]) may appropriately model coordination of activities among 'first responders' at all levels in a confederated structure by enabling federal government emergency response plans to mesh with the regional, state and local counterparts [18]. Visionary companies, such as TheMindElectric, are already looking into the creation of dynamic service infrastructures to support emergence of architectures in Cyberspace that mirror biological behavior.

3.   An Emergent e-Logistics Infrastructure Model Based on a Layered Multi-Agent System Architecture

We start from the observation that the phenomenon of emergence involves:

- *Self-organization* of the dynamical systems such that the synergetic effects can occur

- Interaction with other systems from which the synergetic properties can *evolve*

We build on a recently developed fuzzy-evolutionary model [35] that induces emergence in virtual societies of software agents 'living' in Cyberspace:

1. By minimizing the entropy measuring the (fuzzy) information spread across the multi-agent system it induces *self-organization* with careful clustering of resources (agents) ensuring a good interaction between the system's parts to reach its objectives timely, efficiently and effectively.

2. It enables the system's *evolution* by interaction with external systems (agents) e.g. found via genetic search in cyberspace (mimicking mating with most fit partners in natural evolution) or via the use of dynamic discovery services [3][14][19] (yellow pages, mediators/brokers, etc.).

The integration of the two above mentioned steps of the formalism on a flat, 1-tier (peer-to-peer) architecture via the definition of the fitness function in terms of fuzzy entropy is addressed in [37]. Here we present the extension of the emergence mechanism from a 1-tier to a 3-tier nested (holonic) architecture with intra-enterprise (planning) and physical resource levels, Fig. 2.

Multi-agent systems enable cloning of real-life systems into autonomous software entities with a 'life' of their own in the dynamic information environment offered by today's cyberspace. The *holonic enterprise* has emerged as a business paradigm from the need for flexible open reconfigurable models capable to emulate the market dynamics in the networked economy (cf. [12]), which necessitates that strategies and relationships evolve over time, changing with the dynamic business environment. Building on the MAS-Internet-Soft Computing triad to create a web-centric model endowing virtual communities/societies (generically coined as 'enterprises') with proactive self-organizing properties

in an open environment connected via the dynamic Web, the holonic enterprise paradigm provides a framework for information and resource management in global virtual enterprises (cf. [35]).

3.1 Architecture

According to the above paradigm of holonic (virtual) enterprises, which - from our point of view - is the most sophisticated approach to virtual enterprises, the following three principle layers of collaboration/interaction need to be considered by a MAS in order to emulate a holonic enterprise.

Inter-Enterprise Level

The highest level, the *Global Inter-Enterprise Collaborative Level* or *Inter-Enterprise Level* for short, is the level on which the holonic enterprise is formed. Each collaborative partner is modeled as an agent that encapsulates those abstractions relevant to the particular cooperation. By this, a dynamic virtual cluster emerges that – on the one hand – is supposed to satisfy the complex overall goal at hand as good as possible and – on the other hand – considers the individual goals of each enterprise involved.

Intra-Enterprise Level

Before an enterprise can undertake responsibility for some subtask, it has to find out about its own internal resources to ensure that it can deliver on time according to the coordination requirements of the collaborative cluster and with the required quality. Since this is done within the enterprise at hand we call this level the *Intra-Enterprise Level*. This level covers all layers within an enterprise with the exception of the lowest level, the atomic autonomous system level.

Atomic Autonomous Systems or Machine Level

The lowest level is the *atomic autonomous systems* or *machine level*. It is concerned with the distributed control of the physical machines that actually perform the work. To enable agile manufacturing through the deployment of self-reconfiguring, intelligent distributed automation elements each machine is cloned as an agent that abstracts those parameters needed for the configuration of the virtual control system managing the distributed production.

Each level is represented by one or a number of holons each of which representing a unit on this level. Such a unit recursively consists of a set of holons each of which being responsible for a subtask of the overall task of the holon/holarchy at hand. These "sub-"holons do not need to be from lower levels only, but can as well be holons from the same level. For example, a flexible cell holon may comprise holons representing atomic autonomous systems as well as flexible cells which perform tasks that are necessary for the flexible cell holon at hand to be effective.

Planning and dynamic scheduling of resources on all these levels enable functional reconfiguration and flexibility via (re)selecting functional units, (re)assigning their locations, and (re)defining their interconnections (e.g., rerouting around a broken machine, changing the functions of a multi-functional machine). This is achieved through a replication of the dynamic virtual clustering mechanism having now each resource within the enterprise cloned as an agent that abstracts those functional characteristics relevant to the specific task assigned by the collaborative conglomerate to the partner. Re-configuration of schedules to cope with new orders or unexpected disturbances (e.g. when a machine breaks) is enabled through re-clustering of the agents representing the actual resources of the enterprise. The main criteria for resource (re)allocation when (re)configuring the schedules are related to cost minimization achieved via multi-criteria optimization.

Mediator Holon/Agent

The basic condition for holonic systems is that a holon is simultaneously a "whole" and a "part" of some other whole/holon. Thus the system exhibits a tree-like structure. Each inner node of this tree in fact comprises a set of (sub-)holons that cooperatively work together to solve the specific task that is assigned to this node. In order to communicate with such a set of (sub-)holons one need to define a representative for it. In a MAS environment this representative can be a software agent that undertakes the task of a mediator. It fulfills two main functions. First, seen from the *outside*, it acts as the interface between the agents inside the holon and those outside it; conceptually, it constitutes the agent that represents the holon. Second, seen from the *inside*, it may initiate and supervise the interactions between the group of sub-holons/agents within the holon at hand; this also allows the system architect to implement (and later update) a variety of forms of interaction easily and effectively, thereby fulfilling the need for flexibility and re-configurability. The mediator encapsulates the mechanism that clusters the holons into collaborative groups. The architectural structure in such holarchies follows the design principles for metamorphic architectures.

From the point of view of the mediator agent the first case describes its *outside view* while the second case describes its *inside view*. Both views are significantly different with the outside view usually being much more demanding than the inside view.

Since the mediator is the common representative for the outside world of the holon it represents, as well as for the inside world, it needs to understand both worlds. For this, two kinds of ontologies are necessary, namely for 'peer-to-peer' communication at each level (that is 'inter-agent' communication among entities that form a cluster); and for 'inter-level' communication that enables deployment of tasks assigned at higher levels (by the mediator) on lower level clusters of resources.

3.2 Example Scenario

Let us come back to the catastrophe example of Fig. 1. In case of a catastrophe all possible measures have to be taken in order to keep its effects (especially causalities) as small as possible. Profit in the sense of monetary benefits is not the main goal. Instead, a fast reaction is required. First of all it has to be ensured that all possible resources are allocated as fast as possible. In a next (refinement) step a good coordination of the resources is necessary. Let us assume a crash of a passenger train and have a look at the subtask of coordination of ambulance cars. In a first step it is necessary to ask all of them to drive as quickly as possible to the place where the catastrophe has happened. If necessary other cars that may also be equipped for transporting injured persons may be asked to help. In the next step it needs to be coordinated which and what kind of patients are driven to what hospital. This depends on the capacity of the hospital as well as its specialty and equipment. In these extreme situations the otherwise important system goal that the ambulance cars of hospital X bring the patients only to this hospital has to be suspended and replaced by a strategy which allows optimal distribution of the patients independently of what cars are transporting them.

With respect to our multi-agent system based emergent e-Logistics infrastructure the above requirements mean that the agent being in charge of the transportation and treatment of the injured people (called ambulance agent from now on) needs to react very quickly in the beginning to start the rescue action and then,

on the fly, has to start to more and more optimize the originally pretty abstract and general coordination respectively planning. This requires a flexible adaptation of the overall goals of the agent and their preferences/priorities. After the initial phase of extreme fast responses (which can be translated to an approach closer to pattern matching) the further refinement of the planning procedure needs to consider more and more the real circumstances of the given scenario, therefore, needs to shift from a more reactive to a more deliberative behavior. Police cars need to be sent to the right places in order to make sure that the ambulance cars can drive as fast as possible to the designated hospitals. The personal in the ambulance cars (which can be considered as holons on the lowest level as well) need to diagnose their patients in order to provide a basis for the decision which hospital may be the right one. Then, on the next higher level, it needs to be decided which hospital is effectively chosen (otherwise, if the ambulance car decides, it can happen that too many ambulance cars are driving to the same hospital, thus, overstrain its real-time capacity or the capacity of the streets leading to it). This requires that the ambulance agent defines tasks and delegates them to special agents which can deal with them exclusively. All of this has to be done in a step by step refinement process which needs to consider all the influences by all the other measures that are to be taken to deal with the catastrophe (e.g. the coordination of other kinds of vehicles that are needed to get access to injured people or, e.g., to extinguish fire or avoid environmental catastrophes (oil leakage)).

In this paper we will deal with several aspects of the above scenario. First of all we will discuss what kinds of mediator agents are needed in an emergent holonic enterprise since the above observation requires designing mediators on different levels differently (section 3.4). Next we will address the problem how different kinds of goals can be deeply embedded in an agents belief system and how the belief system can be modeled in a way that it can react in different ways (faster more automatic (reactive) response versus deliberate, however, slower response; section 3.5).

3.3 Expression of Semantics

One main obstacle to the meaningful interoperation and mediation of services is the syntactic and semantic heterogeneity of data and knowledge the mediator agent does access and receive from multiple heterogeneous agents (cf. [20]). The functional capability of the agent to resolve such heterogeneities refers to the knowledge-based process of *semantic brokering*. Most methods to resolve semantic heterogeneities rely on using partial or global ontological knowledge[1], which is to be shared among the agents. This requires a mediator agent to provide some kind of ontology services for statically or dynamically creating, loading, managing, and appropriately using given domain-specific or common-sense ontologies as well as inter-ontology relations when it wants to communicate and negotiate with different agents or understand complex tasks.

In fact a mediator agent that is looking for a specific task (service provider) has to parse, understand and validate the offers/service descriptions it gets. This is in order to efficiently determine which of the services and capabilities of other enterprise/holon agents are most appropriate. Typically for this ontol-

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[1]An *ontology* is a computer-readable representation of the real world in form of objects, concepts, and relationships.

ogy services are used as well. Depending on the complexity and required quality of the service a matching process may rely on simple keyword and value matching, use of data structure and type inferences, and/or the use of rather complex reasoning mechanisms such as concept subsumption and finite constraint matching. Semantically meaningful matching requires the matching service to be strongly interrelated particularly with the class of services enabling semantic interoperation between agents.

In emergency logistics, where the scope of possible organizations/tasks/skills is not restricted and/or predefined, it is difficult to express and code enough real world semantics to permit a goal-driven and effective communication between levels. We are fully aware that the expression and understanding of semantics is still a hot topic in research with sufficient general solutions even not being on the horizon. However, this does not prevent us from deploying our concepts in more restricted and better addressable application areas.

So, our current approach is to use for the expression of semantics and for proper communication between levels within and across organizations already developed real-world knowledge models and ontologies [11][21][14][34][33] like DAML-OIL, respectively it successor DAML-S. Since FIPA is working on concepts to integrate agents and Web-Services we will adapt their solution to our scenario as soon as the results are available.

3.4 Discovery, Selection and Assembly (Workflow) of Cross-Enterprise Services

In order for the emergent e-Logistics Infrastructure to be operational we first of all need to develop a mechanism enabling the discovery of new partners/collaborators in Cyberspace, by using state-of-the-art approaches for coalition formation (acquaintance models) and dynamic service discovery and composition [1][2][3][7][14][17] by a mediator agent that has to fulfill (a subset of) the following tasks:

- to understand and interpret the complex task at hand (overall objective of the holonic enterprise)
- to decompose it into sub-tasks that can be dealt with by individual enterprises
- searching for and finding possible partners
- organizing the negotiation process and dealing with possible contractors/participants
- controlling and supervising the execution of the (sub-)tasks
- reacting to and solving emerging (unexpected) problems
- storing and maintaining a knowledge base in which experiences of the performance and efficiency of past holonic enterprises and its members are stored

These are very special abilities by which the mediator agent is to be equipped. In the following we will first discuss the principle ways in which a mediator may search for/find the appropriate partners.

Types of Mediator Agents in a Holonic Enterprise
In principle a mediator may engage a broker/facilitator, a matchmaker, may use yellow page services or may rely (totally or partially) on its acquaintances knowledge base.

If a (mediator) agent, that is looking for some service, uses a *broker service* it gives up control about the selection process and about the knowledge in what way which enterprise has contrib-

uted to the solution process. It fully depends on the quality and sincerity of the broker service. *Matchmaking* already allows the mediator agent to keep much more control about the choice of the participating agents since the mediator agent only gets a list of enterprises that are in principle capable to provide some service for the solution process. However, it is left to the mediator agent to decide on what service/enterprise is to be chosen. The most independent approach is that an agent maintains its own database of *acquaintances* in which all possible cooperation partners along with their capabilities and past experiences with them are stored. The agent will always first try to find appropriate partner agents in this database. Only if this is not successful it will deploy one of the other possible services. While this approach promises the most independence of an agent from its environment it also requires a pretty sophisticated agent architecture since the agent needs to fully understand the overall goals and requirements of the requests it is supposed to find a solution for.

The most important level is the inter-enterprise level since here the foundation for a successful holonic enterprise is laid. It is mandatory that the initiator agent of a holonic enterprise has the ability to be in full charge of the creation and operation process of the holonic enterprise. This is not only necessary to guarantee that the potential members of the holonic enterprise fully agree on the objectives of the holonic enterprise but it is also necessary to profit in the future from experiences made during the time of existence of the holonic enterprise. Which member performed in what way? How flexible/ motivated/dedicated/passionate/ efficient/effecttive/competitive/trustworthy were they? All these experiences can help to form even better holonic enterprises in the future. This requires the mediator agent to be capable to understand and dissolve complex tasks, to negotiate with possible partners, to control the operation of the holonic enterprise and, especially, to judge its success and the role which each member of the holonic enterprise has played in achieving the results. To meet these demands the mediator agent of a holonic enterprise has to maintain its own database of acquaintances and experiences/history. Additionally, in order to improve the overall performance of the holonic enterprise and to react to ever changing demands of the market it may make use of matchmakers respectively yellow pages. Since the overall objectives of a holonic enterprise may be far beyond the expertise, knowledge and capabilities of the holonic enterprise the mediator is a representative of, it is necessary that the mediator can understand and interpret semantics in a broad area (possesses a broad world model). We will discuss how this can be realized in the next section when we discuss Web Services and the Semantic Web.

In contrast to that the scope/knowledge/capabilities of a mediator agent on the *intra*-enterprise level do(es) not need to be that brilliant. The area of expertise is limited, namely constraint to the area of expertise of the holonic enterprise at most. The set of possible partners is restricted as well because these are first of all other units within the enterprise. More specifically, a holon deals in its outside view with holons on the next higher level of the architecture while it deals in its inside view with the (sub-) holons that constitute the holon at hand.

Of course, in case of emergencies (machine break-down) or simply because a needed capacity/service/capability is not available even on the intra-enterprise level the necessity may arise to publicly advertise a task/service in the outside world. However, in this case the mediator may make use of a broker in order to settle

and process the transaction at hand. The broker can, of course, as well be the mediator agent representing the enterprise at hand.

As we move down the layers of a holonic enterprise we can observe a decrease with respect to the following features:

Time Scale
From top to bottom time scales become shorter and real-time constraints change from soft to hard real-time. While, e.g., a formation process of a new holonic enterprise on the inter-enterprise level may take a longer time and time pressures are only soft (more deliberative style of agent) an agent that represents a tool needs to usually react extremely fast (more reactive style of agent that reacts directly to patterns ("prefabricated" reaction)).

Complexity/Sophistication
From top to bottom the degree of agency decreases. The higher level agents are more sophisticated but slower, while lower agents are fast and light-weight. For example, the mediator agent that represents an enterprise needs to have a very broad knowledge and a huge number of sophisticated skills. On the contrary, the agent on the level of an atomic system just needs to have an understanding of this system together with some basic skills to communicate with the next higher level agents.

Autonomy
Since each agent will act according to its own goals conflicting situations may occur when a contacted agent does not want to contribute (fully) to the task at hand (due to overload, preference/priority given to more lucrative offers, etc.). In this case the superordinated (higher-level) agent has to decide on how to deal with such obstacles and, if possible, to develop an alternative solution on the basis of all the information obtained from all its subordinated agents (using its knowledge base and goals). Especially, in emergency cases it may be necessary to compromise the autonomy of agents completely. Again, agents that represent an enterprise will be fully autonomous and, therefore, cannot be forced from the outside to do something they do not want to do. On the intra-enterprise level the autonomy will decline with decreasing level. If, e.g., a task was accepted for which a high <u>contract</u> penalty is to be paid in case it is not finished in time the holon in charge may decide that the subordinate holons have to execute some task first in order not to risk a delay of the high-priority task, even if the lower level holons are already fully booked with other tasks.

The above observation requires designing mediators on different levels differently. We will come back to this topic in the next section when we will discuss how outside goals (that are imposed on an agent from the outside world) and inside goals (the goals of an agent) can be harmoniously integrated.

3.5 Intentional Problem Solving
In general, a multi-agent system consists of a set of autonomous agents; all of them are equal [14]. To realize a layered three-tier holonic enterprise (Fig. 2), the usual capability of individual agents to express and represent their own goals has to be enhanced with an integration mechanism synchronizing individual goals with those of the higher levels in the extended enterprise. More specifically, this section will discuss what kind of goals need to be deeply embedded in a (mediator) agent's belief system in order for it to be capable to truly represent its underlying holon on the one hand and consider the goals of the environment it is embedded in on the other hand and how this can be realized.

We will concentrate on a single organizational unit and its (problem solving) behavior. Such a unit can be a profit-center (on the level of production planning, shop floor or flexible cell) or an individual corporation. In order to provide complex products or service bundles, first of all, a comprehensive planning process is to be performed. To achieve flexibility and dynamicity the process needs to rely on the concept of modularized capabilities. Thus planning enables the identification of those elementary products or services that can be combined for product or service bundles. As is illustrated by Fig. 3 planning can be performed *top-down*, that is, by problem decomposition[2], or *bottom-up*, that is, by service or product aggregation.

To find *the* optimal solution for such a kind of planning is in general an NP-hard problem. By exploiting heuristics/experiences we aim to overcome the limitations of existing approaches [14][16] [19], especially regarding the timely response constraint required by emergency.

In general, during a planning process, from the perspective of the organizational unit that alternative has to be chosen that promises the highest profit[3]. Therefore, the organizational unit has to open up its planning for this profit dimension in order to behave (economically) reasonable. Consequently, two different kinds of goals can be distinguished and described: *output* and *system* goal. According to [15] the former stands for the plan goal that is to be achieved, that is the problem that has to be solved. The latter describes the real purpose of the organizational unit, which often means profit maximization.
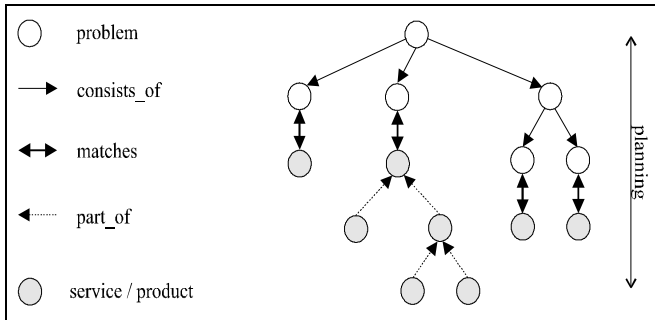

Fig. 3. Planning

An agent that represents such a unit must consider both goals. Systems showing a behavior that is dependent on certain goals in a reasonable way are characterized as intentional [5]. Intentionality is a key characteristic of agent-based technology. In addition agent methodology genuinely addresses planning respectively deliberative behavior [42] and cooperation.

The coexistence of two kinds of goals that have both to be considered by the generated plan necessitates a two-staged planning process. Due to the overriding importance of the system goal in comparison to the output goal the traditional planning process

that mainly concentrates on the realization of the output goal has to be revised in a way that it reflects the system goals in an appropriate way. However, system goals, to become effective, must strongly influence the planning process as such. Planning processes can best be influenced if they are controlled by meta-planning processes, that is, processes on a more abstract level. In such an architecture the basic problem solving behavior of an agent can be illustrated as in Fig. 4. It visualizes the interdependencies between the most important entities involved.
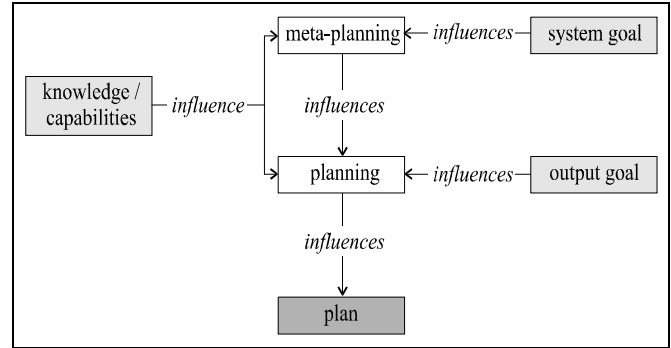

Fig. 4. Meta-Planning versus Planning

An in-depth discussion of both planning and meta-planning procedures is beyond the scope of this paper, especially since traditional planning has already been intensively studied in literature. Instead, we will only concentrate on meta-planning. Meta-Planning has to ensure that, based on the system goals, a rational choice can be made among planning actions that constitute alternatives[4] with respect to the given output goal. Consequently meta-planning has to control the planning process either in a dynamic or in a static manner:

- *Dynamic* meta-planning stands for the direct control of the planning procedure. This means that whenever the planning process has to make a choice among alternative decompositions or, correspondingly, among alternative products or services the meta-planning process will determine the one from which it assumes that it is the most appropriate one with respect to the system goals.

- *Static* meta-planning describes the procedure where first of all a number of relevant alternative plans are generated. Subsequently that plan is chosen that reflects the system goals best. This corresponds to an extensive, however, non exhaustive[5] search through the set of all possible plans. This set represents the overall search space and is obviously relatively complex.

Both alternatives operate analogously on two subsequent levels of aggregation: Depending on the respective system goal both select one element from a set of alternatives. Dynamic meta-planning does so for a set of decompositions respectively services

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[2] It is important to understand that the decompositions have to completely cover the original problem. If, as a result of the decomposition process, a subsequent synthesis is required, it has to be encoded in one of the sub-problems.

[3] In this section we will use the word profit as a simplified expression for the overall goal of a holonic unit. Profit has to be interpreted in a very broad sense. It may mean monetary profit as well as to save lifes by reacting as quickly as possible without considering possible costs.

[4] This choice among alternatives does not comprise all choices that are available to the planning procedure. Alternative in this context means that the respective products or services are likewise applicable within a given planning stage. Without meta-planning the planning procedure would use heuristics to decide on one of them, because from a planning perspective they equally serve the output goal. Otherwise meta-planning would actually comprise planning.

[5] An exhaustive search would be NP-hard.

or products whereas its static counterpart works on a set of plans that again constitute a set of decompositions and products or services. Since the system goal has to enable a total ordering of the alternative elements it has to be defined by referencing some of their characteristics (e.g., profit contribution of each product). Consequently, system goals can be distinguished according to the kind of element they refer to. Thus dynamic meta-planning requires a system goal that is located at a decomposition / product or service level and static meta-planning necessitates system goals that are situated at plan level. By continuing analogously the aggregation by combining alternative plans we get to a system goal at a plan-set level.

Within the scenario of this paper such system goals can be formulated as follows:

Decomposition / product or service level:

i. "Make as much profit as possible by preferring certain products/services."

Plan level:

ii. "Make as much profit as possible from each task respectively problem."

Plan-set level:

iii. "Make as much profit as possible within a certain period of time."

Achieving a system goal at the plan-set level would constitute an "ex-post" meta-planning and can consequently not be implemented directly, because a runtime control of the planning procedure can only be realized by applying either dynamic or static meta-planning. However, both require system goals located at "lower" levels, i.e., plan or decomposition / product or service level. This motivates a top-down transformation of system goals that in general cannot be performed unambiguously[6] and consequently requires the use of heuristics[7].

ad i. Dynamic meta-planning can be applied, e.g. by prioritizing the decompositions respectively products or services so that the planning procedure obey the system goal as far as possible. This means it will apply the specific decomposition or use the specific product whenever possible for a given problem.

ad ii. Either static or dynamic meta-planning can be applied. Static meta-planning simply has to evaluate all plans that have been generated for the problem at hand and has to select the most profitable one. Dynamic meta-planning would have to rely on heuristics, since the system goal cannot be implemented directly at the product level. Such a heuristic could be to prefer always the most profitable product among a set of alternative ones.

ad iii. Either static or dynamic meta-planning can be applied but both have to rely on heuristics. Such a heuristic could be to prefer always the cheapest plan for the customer based on the assumption that most profit can be made if as much cus-tomers as possible can be attracted by extremely attractive offers. Static meta-planning would consequently select the cheapest plan out of the set of alternatives. Dynamic meta-planning would have to rely on a further heuristic, since the former cannot be implemented directly at the decomposition / product or service level. This second heuristic could analogously prefer always the cheapest product among a set of alternative ones.

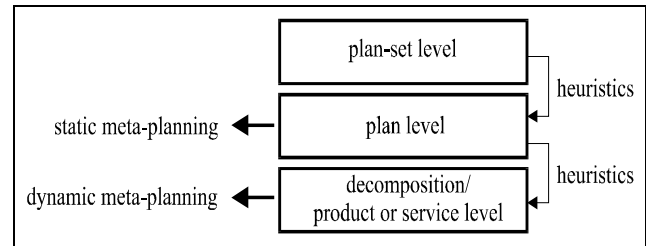Fig. 5 summarizes and visualizes the respective kinds of system goals.

Fig. 5. System Goal Classification

Up to now we have (implicitly) concentrated on the highest level, the inter-enterprise level. If we want to apply the discussed concept of goal implantation on lower level mediator agents as well we need to consider the ranking/importance of the goals for these kinds of agents. For example, the mediator agent representing an enterprise needs to be highly autonomous, which means that it only acts strictly according to the objectives of its enterprise and cannot be prevented by some else to do that. This clearly indicates that goals of the agent need to be modeled as system goals. On the other hand, the agent representing an atomic system/machine has low autonomy. Only if the superordinated levels do not intervene it can react strictly according to its own goals. Therefore, here the goals of the agent need to be modeled as output goals. A more detailed discussion of intentional problem solving can be found in [38].

4. Conclusions

In this paper we have proposed a model for an emergent e-Logistics infrastructure for timely emergency response management by collaborative problem-solving. We have shown what kind of mediator agents are necessary in such an infrastructure and how the difficult task of flexible and dynamic goal representation on the agent level can be dealt with. The proposed e-Logistics model is applicable to a wide range of problems requiring timely configuration and coordination of distributed resources needed to address emergency situations as: *disaster emergency logistics* (evacuation planning, scheduling of emergency relief crews, food and water distribution, hospital bed planning); *national defense and security* (emergence of military holarchies as infrastructure for coordination of military operations in case of an unexpected attack); *ubiquitous ad-hoc healthcare* (emergence of a medical holarchy grouping the most suitable medical entities able to cooperate and organize their interaction to respond adequately to patient's need; medical emergency logistics with patient information retrieval and heterogeneous transaction workflow management throughout the medical holarchy); *fault-tolerant flexible production* (emergent planning and scheduling of reconfigurable manufacturing production; customer-centric supply chain and

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6 In general it is not possible to derive the most profitable plan by simply choosing the most profitable decomposition or activity among emerging alternatives.

7 Algorithm that can not guarantee an optimal performance in any case but an improvement for the average-case performance [[16], p. 94].

workflow management; fault tracking and error reporting across the manufacturing holarchy).

Future Work

In order to learn from real experiences we intend to distribute a large scale reference software platform across Canadian GAIN Nodes (to be later extended across the Global Agentcities Nodes) enabling the creation and deployment of emergency e-Logistics applications. The ultimate goal is

- to validate the emergence methodology first on a simple e-Logistics simulation test case - using and extending FIPA compliant multi-agent platforms
- to build a prototype for a medical emergency application
- to generalize the methodology into a reference model enabling quick deployment of emergency e-Logistics applications capable to integrate heterogeneous devices, resources and organizational structures into a synergetic collaborative unit synchronizing individual goals with the goals of the superordinated unit(s) at the higher level(s).

In the long term we aim to make this methodology the international standard in e-Logistics. For this we will integrate the results obtained working cooperatively with the international consortia into a *reference software platform for emergency e-Logistics*.

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