# A Goal-Oriented Approach for Self-Configuring Mashup of Cloud Applications

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*Abstract*—**This paper presents a general approach for automatic composing mashups of applications distributed over the cloud. The approach implies to wrap existing services in smart and autonomic entities, namely cloud capabilities. These are able to interact and coordinate themselves in order to establish different ways to orchestrate their contained services. The main enabler of this technology is based on an explicit distinction between user's goals and the way to address them. A couple of language has been adopted to describe respectively the mashup logic in terms of goals and the available functionalities in terms of capabilities. A running example has been developed for extending B2B business processes of a fashion enterprise.**

## I. Introduction

The market turbulence of recent years is an indication of a new phase of globalization, one in which the ability to satisfy customer expectations in a quickly changing environment is the core differentiator for enterprises [1]. Companies require ways to make their processes more flexible opening, at the same time, their business process to the direct access of users.

Technology can play an important supporting role in enabling organizations to become more agile. In particular, Cloud computing focuses on maximizing the effectiveness of shared resources and information (that are provided to users on-demand) reducing the overall cost by using less power, air conditioning, rack space, etc.

Despite the fact that Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access, Cloud applications are currently developed as monolithic solutions tethered to proprietary stack architectures in which the provider typically runs all elements of the service [2]. These architectures may represent a barrier for third-part developers to mix and match services freely from diverse cloud service levels to configure them dynamically to address application needs [2].

The objective of *Cloud Application Mashup* is to enable easier customization and composition of SaaS applications from several providers by providing a cohesive solution that offers improved functionality to clients. The mashup task involves complex protocols with an automatic data and process integration, and preserves global application consistency.

So far, mashup is mainly intended as an instrument for web developers for integrating content from more than one source in a new single graphical interface. A representative example is HousingMaps (http://www.housingmaps.com), which combines rental listings from a popular advertisements website with Google Maps for providing a visual representation of local apartments for rent. Other common examples are online magazine that include buttons for social sharing (for instance: The New York Times (http://www.nytimes.com), CNN.com (www.cnn.com), BBC (http://www.bbc.com).

Now we are moving towards a variety of web service that run over the Cloud as SaaS. Notable examples are: Google Applications, Dropbox, Microsoft Office365, the mashup technology is evolving for mixing processes together with data and user interfaces.

This paper presents an approach for automatically generating Cloud Application Mashup. The vision is that Mashups are created for the consuming user, often directly by the users themselves, so that they can take advantage of software licensing and billing model based on the pay-per-use concept. Therefore users will establish or modify situational collaborations for integrating services from a variety of cloud providers. Cloud services should be available on public cloud marketplace in which providers store their offerings. Clients can discover and buy the needed services to use for their own mashup. Therefore, a mashup self-composition engine should act as a run-time mediator between user's goals and atomic cloud services in order to realize the desired mashup application.

In recent works we have adopted GoalSPEC [9], a goal-oriented [3] language in order to describe the expected behavior of a complex distributed system in terms of states to be addressed. The algorithm for automatically selecting and aggregating services in order to address user's goals has been presented in [11]. However the main limit of that algorithm relies on the centralized logic and in particular it is the difficulty in scaling up for an increasing number of goals and services.

The main contribution of the paper is a three-layer architecture for implementing Cloud Capability and supporting cloud application mashup. A cloud capability is a smart and autonomous container of traditional web services. It is a lively application, running at SaaS level, inspired by the principle of autonomic computing: sensing the environment, making proactive decisions and interacting with other cloud capabilities in order to organize a coordinated behavior. To enable the automatic composition of services, these must be available together with relevant aspects for their integration and usage through ad-hoc description languages. We adopted a capability description language that exploits predicate logic in order to specify when and how to use a service. Decoupling the specification of what the system has to do (user's goals) from how it will be done (capabilities) allows the self-configuration engine to compose the expected behavior on the occurrence.

As a running example we report the case of cloud mashup built for a fashion enterprise. The B2B process is described through a set of goals that are introduced into the system thus to become a stimulus for self-configuring ad-hoc solution.

The marketplace has been instrumented with a sufficient set of services for addressing the request. Therefore, by exploiting their self-configuration protocols, it is responsibility of the corresponding cloud capabilities to configure the expected B2B mashup.

We envisage this approach could have substantial impact for IT by improving the return-on-assets of the existing systems. Self-configured Mashup is a facilitator for fast and flexible B2B collaboration (short development cycles, cheap development) whereas existing B2B collaboration solutions focus on long-term business relationships [4]. Short and cheap development cycles make B2B solutions available for small and medium enterprises.

The paper is organized as follows: Section II presents the main concepts of the approach: state, goal, capability and configuration. Section III presents a real scenario occurred during a research project and introduces the elements for enabling the self-configuration. Section IV illustrates details of the self-configuration module: the three layer-architecture and the cloud capability. Section V focuses on the self-configuration distributed process, whereas Section VI explains the dynamic workflow generation related to a mashup. Related works are discussed in Section VII whereas conclusions are given in Section VIII.

## II. Preliminary Definitions and Concepts

In this subsection we introduce some of the main concepts that are used along the paper.

A ***State of the World*** is an abstraction made to let the system reasoning at the knowledge level [5]. It arises from the consideration that a software system has (partial) knowledge about the environment in which it runs. The classic way for expressing this property is (Bel $a$ $\varphi$) [6] that specifies that a software agent $a$ believes $\varphi$ is true, where $\varphi$ is a fact that describes a generic state of affair. This is similar to the concept of fluent found in situation calculus. The definition of relevant and coherent states of the world requires a preliminary analysis of the domain that is perfectly captured in a ontology describing classes, properties and individuals of interest. The proposed approach is independent on the specific instrument chosen to model the domain (e.g. OWL-S [7], POD [8]).

*Definition 1 (State of the World):* The state of the world in a given time $t$ is a set $W_t \subset S$ where $S$ is the set of all the non-negated facts $s_1, s_2 \dots s_n$ that can be used in a given domain.

$W_t$ has the following characteristics:

$$W_t = \{s_i \in S | (\text{Bel } a \; s_i)\} \qquad (1)$$

where $a$ is the subjective point of view (i.e. the execution engine) that believes all facts in $W_t$ are true at time $t$.

A ***Capability*** is a self-contained process, which can access and modify the current state of the world. These are used as wrappers for coordinating existing cloud applications and services. The capability also has the advantage of being composable in order to address a complex result.

*Definition 2 (Capability):* A capability $\langle evo, pre, post \rangle$ is an atomic and self-contained action the system may intentionally use to address a given evolution of the state of the world. The evolution, denoted as $evo : W \rightarrow W$ is an endogenous change of the state of the world that takes a state of the world $W_t$ and produces a new different state of the world $W_{t+1}$ by manipulating statements in $W_t$. The capability may be executed only when a given pre-condition is true ($pre(W_t) = true$). Moreover, the post-condition is a run-time helper to check if the capability has been successfully executed ($post(W_{t+1}) = true$).

The concept of ***Goal*** is often used in the context of business processes for representing enterprise strategic interests that motivate the execution of a specific workflow [3]. It is "a desired *change* in the state of the world an actor wants to achieve".

*Definition 3 (Goal):* A goal is a pair: $\langle tc, fs \rangle$ where *tc* and *fs* are conditions to be evaluated over a state of the world. Respectively the $tc$ describes when the goal should be actively pursued and the $fs$ describes the desired state of the world. Moreover, given a $W_t$ we say that

$$\text{the goal is } \textit{addressed} \text{ iff } tc(W_t) \wedge fs(W_{t+k}) \text{ where } k > 0 \qquad (2)$$

i.e. a goal is addressed if and only if, given the trigger condition is true, then the final state must be eventually hold true somewhere on the subsequent temporal line.

The user should specify his mashup application by means of a goal-set.

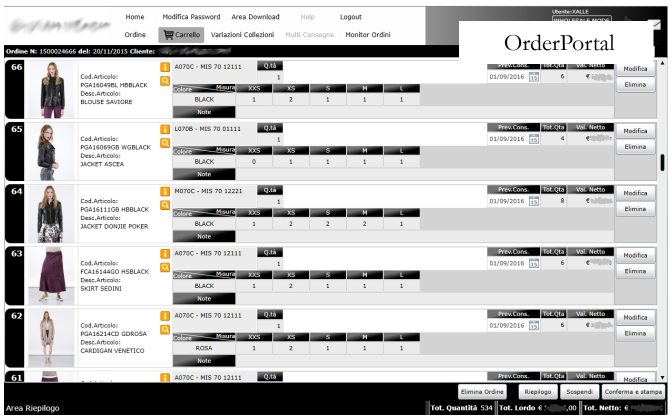
A ***Configuration*** is defined as a set of tuples of type $\langle g, h \rangle$ that fully address the goal-set specified by the user, where for each goal $g$ of the goal-set, $h$ is a simple or composed capability selected for addressing it. In other words a configuration associates each goal of the goal-set with a simple or composed capability. The main property of a configuration is that executing its capabilities will address the whole goal set. Section VI provides details about how to convert a configuration into a executable workflow.

Section V illustrate the central part of the paper, i.e. how system may generate configurations as response to user's goals.

## III. An Example of Cloud Application Mashup

This section provides an overview of the self-configuration process by means of a running example extracted from the activities conducted in the OCCP research project[1].

[1]The OCCP project web-page is available at http://aose.pa.icar.cnr.it/OCCP/



Ordine N: 1500024666 del: 20/11/2015 Cliente: [redacted]

66 Cod.Articolo: PGA16049BL HBBLACK Desc.Articolo: BLOUSE SAVIORE — A070C - MIS 70 12111 — Q.tà 1

| Colore / Misura | XXS | XS | S | M | L |
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| BLACK | 1 | 2 | 1 | 1 | 1 |

| Prev.Cons. | Tot.Qta | Val. Netto |
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| 01/09/2016 | 6 | € [redacted] |

65 Cod.Articolo: PGA16069GB WGBLACK Desc.Articolo: JACKET ASCEA — L070B - MIS 70 01111 — Q.tà 1

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64 Cod.Articolo: PGA16111GB HBBLACK Desc.Articolo: JACKET DONJIE POKER — M070C - MIS 70 12221 — Q.tà 1

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| 01/09/2016 | 8 | € [redacted] |

63 Cod.Articolo: FCA16144GO HSBLACK Desc.Articolo: SKIRT SEDINI — A070C - MIS 70 12111 — Q.tà 1

| Colore / Misura | XXS | XS | S | M | L |
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| Prev.Cons. | Tot.Qta | Val. Netto |
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| 01/09/2016 | 6 | € [redacted] |

62 Cod.Articolo: PGA16214CD GDROSA Desc.Articolo: CARDIGAN VENETICO — A070C - MIS 70 12111 — Q.tà 1

| Colore / Misura | XXS | XS | S | M | L |
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| ROSA | 1 | 2 | 1 | 1 | 1 |

| Prev.Cons. | Tot.Qta | Val. Netto |
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| 01/09/2016 | 6 | € [redacted] |

61 A070C - MIS 70 12111 — Q.tà

Tot. Quantità 534 | Tot. Lordo € [redacted],00 | Tot. Netto: € [redacted]

Fig. 1. Screenshot of the website hosted and managed by the OrderPortal Capability.

### A. A B2B Cloud Application for Fashion Firms

A world known fashion enterprise, here named FashionFirm for privacy reason, uses a legacy system (IBM AS/400) for managing its information system. In order to enlarge its commercial network, FashionFirm designated a small software house, denoted as SWHouse, for handling its B2B processes. SWHouse developed a system on a set of services running on a cloud stack. That is, a set of scalable backend services able to interact with the legacy system from one side and with a SaaS eCommerce platform (OrderlPortal) from the other side. SWHouse is demanded also to enrich the FashionFirm business process by adding new services for customer management.

These new services are conceived as mashup of cloud application with the aim to improve the costs-benefit ratio. In fact, this allows SWHouse to fast prototype the solution reusing already existing cloud application provided by third parts (Cloud Calendar, File Storage, Voicemail ...). The resulting mashup application that will be used as running example in this paper is designed for supporting customers during the order management process. In particular, RetailStore is a retailer of FashionFirm products. When RetailSore requests for a product stock through the OrderPortal, the system merges the legacy services with external applications provided by cloud computing providers: a Cloud Storage system is used for storing and delivering receipts to RetailSore, Voicemail for communicating the delivery status and, finally, a Cloud Calendar service for annotating the delivery status.

### B. Elements for Self-Configuration

The domain expert has to choose the entities and the related properties necessary to model the above scenario. This conceptual model of a domain is rendered as an ontology and it is composed of ***entities***, entity's ***properties*** and ***is-a***, ***has-a*** relationships. The entities and related properties used in the running example are reported in the following list:

```
entities:
   role, document,
   user [is-a role],
   storehouse_manager [is-a role],
   order [is-a document],
   invoice [is-a document],
   delivery_order [is-a order],
   rxfile [is-a URL]

unary user's properties:
  registered,
  has_cloud_space

unary document's properties:
  uploaded_on_cloud

unary order's properties:
   available, accepted, refused

binary properties:
   notified(document,user),
   mailed_perm_link(document,user) [is-a notified]
```

For instance the class user denotes FashionFirm's users, whereas the class order denotes a complex description of items and quantity that a user wants to buy from FashionFirm.

The developer uses the ontological description of the scenario for defining the desired mashup by means of a set of ***goals*** to pursue. An automatic tool for deriving the Goal decomposition from an ontological model is reported in [8], whereas a language for describing GOAL is reported in [9]. The corresponding GoalSPEC definition for the running example is reported in the following list:

```
GOAL to_wait_order:
  WHEN MESSAGE order RECEIVED FROM THE user ROLE
  THE SYSTEM SHALL ADDRESS available(order)

GOAL to_notify_invoice:
  WHEN available(user) AND available(invoice)
  THE SYSTEM SHALL ADDRESS
  MESSAGE invoice SENT TO THE user ROLE

GOAL to_deliver_order:
  WHEN MESSAGE invoice SENT TO THE user ROLE
  THE SYSTEM SHALL ADDRESS
  MESSAGE deliveryorder SENT TO THE storehouse_manager
      ROLE

GOAL to_notify_failure:
  WHEN available(order) AND refused(order)
  THE SYSTEM SHALL ADDRESS
  MESSAGE failure SENT TO THE user ROLE
```

In the above listing, all the words in upper case are keywords of GOALSpec language whereas the word in lower case are entities or properties anchored to the ontological description. The GOALSpec description specifies what should be done for ensuring the correct execution of the order management process.

It is clear that there must be a cloud application or a combination of cloud applications that effectively satisfies each single goal. In order to automatically select and bind services to user's goals, the self-configuration requires additional information about available services. This meta-data is provided by means of the ***capability*** language.

First, the order must be processed via the eCommerce website (`order_portal`). The *OrderPortalMonitor* Capability is responsible of hosting the website and to wait for new orders from users.

```
CAPABILITY OrderPortal:
  Pre-Condition: --
```

```
    Post-Condition: available(order)
    Evolution: [add(available(order))]
```

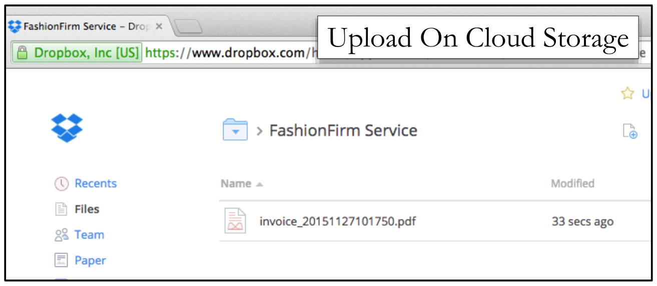
A screenshot of the eCommerce website managed by this capability is shown in Figure 1.

The availability of products in the FashionFirm storehouse must be controlled by means of the *CheckStoreHouse* capability.

```
CAPABILITY CheckStorehouse:
  Pre-Condition: available(order)
  Post-Condition: accepted(order) OR refused(order)
  Evolution: [add(accepted(order)),add(refused(order))]
```

If the requested products are available, the corresponding invoice should be delivered through the *UploadOnCloudStorage*. In alternative, the invoice is stored locally and a link will be communicated to the user via mail). Figures 2 and 3 show respectively the *UploadOnCloudStorage* working with the commercial Dropbox API[2] and the *ShareFileLink* that uses Google Drive services[3] to send the notification.

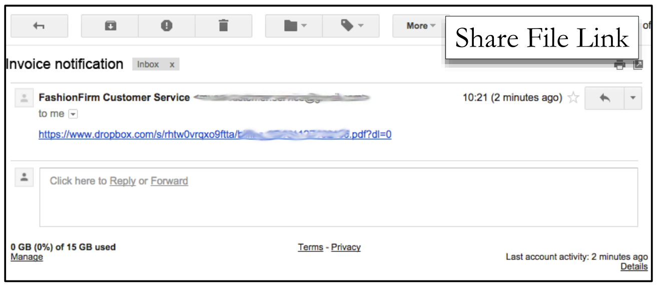
```
CAPABILITY UploadOnCloudStorage:
  Pre-Condition: available(invoice)
  Post-Condition: uploaded_on_cloud(invoice)
  Evolution: [add(uploaded_on_cloud(document))]

CAPABILITY ShareFileLink:
  Pre-Condition: uploaded_on_cloud(document)
  Post-Condition: mailed_perm_link(document,email)
  Evolution: [add(mailed_perm_link(document,email)),
              add(sent(document,user))]
```



FashionFirm Service – Drop ×
Dropbox, Inc [US] https://www.dropbox.com/h
Upload On Cloud Storage
FashionFirm Service
Recents
Files
Team
Paper

| Name ▴ | Modified |
|---|---|
| invoice_20151127101750.pdf | 33 secs ago |

Fig. 2. Screenshot of the front-end of the *UploadOnCloudStorage* Capability implemented through the Dropbox services.



Invoice notification

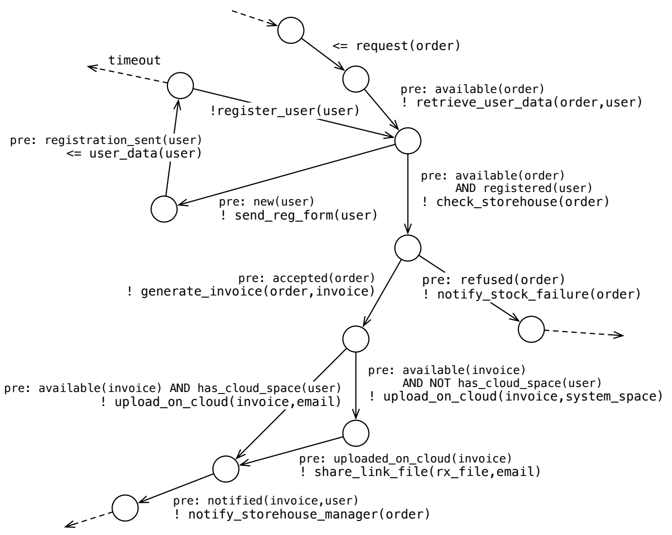
FashionFirm Customer Service [redacted]
to me
10:21 (2 minutes ago)
https://www.dropbox.com/s/rhtw0vrqxo9ftta/[redacted].pdf?dl=0

Click here to Reply or Forward

0 GB (0%) of 15 GB used
Manage
Terms - Privacy
Last account activity: 2 minutes ago
Details

Fig. 3. Screenshot of the front-end of the *ShareFileLink* Capability realized through the Google Apps service.

[2]https://www.dropbox.com/developers-v1/core/docs
[3]https://developers.google.com/drive/v2/reference/



<= request(order)
timeout
!register_user(user)
pre: available(order)
! retrieve_user_data(order,user)
pre: registration_sent(user)
<= user_data(user)
pre: new(user)
! send_reg_form(user)
pre: available(order)
AND registered(user)
! check_storehouse(order)
pre: accepted(order)
! generate_invoice(order,invoice)
pre: refused(order)
! notify_stock_failure(order)
pre: available(invoice)
AND NOT has_cloud_space(user)
! upload_on_cloud(invoice,system_space)
pre: available(invoice) AND has_cloud_space(user)
! upload_on_cloud(invoice,email)
pre: uploaded_on_cloud(invoice)
! share_link_file(rx_file,email)
pre: notified(invoice,user)
! notify_storehouse_manager(order)

Fig. 4. Transition system for the B2B scenario. Transitions are due to cloud capabilities. Prefixes ! and $<=$ indicate respectively an internal event (i.e. the execution of a service) and and external event (i.e an incoming message).

It is worth to detail the link between capabilities and web services. During the self-configuration phase all the available capabilities in the repository are automatically checked against their compatibility to the requested goal. The way the automatic self-configuration happens is reported in Section V. The chosen capabilities are linked to the corresponding web services during the orchestration phase (Section VI).

## C. Resulting Configurations

The self-configuration phase consists in building the state transition system by exploiting available capabilities. A state transition system is a common model used to formally depict the behavior of discrete systems. The self-configuration phase manages the dynamic binding between goals and capabilities by building a state transition system. This transition system is exploited for configuring a suitable system behavior for the assigned goal-set.

A relevant part of the transition system for the B2B scenario is reported in Figure 4. This graph's nodes represent possible (stable) states of the system. The transition from a state to another state is either due to an external event (denoted with $<=$) or due to the execution of a web service (internal event, denoted with !). Initially the system is in a state in which it waits for user orders from the `order_portal` service. When an order incomes then the system retrieves user's data from a database. Here, if the user is not already registered then the system initializes a registration procedure (`send_reg_form` and `register_user` services), otherwise the order is checked over the storehouse database (`check_storehouse` service) thus to be processed until the ordered products are ready to be delivered (`notify_storehouse_manager` service).

An interesting part of Figure 4 is that in which the invoice is ready to be sent (after the `generate_invoice` service) and the system must send it to the user. Here, combining the available capabilities, the system has two choices: either to directly upload the file on the user's cloud storage (`upload_on_cloud` service) or to locally store the file and to send a mail containing the file's url (obtained by combing the `upload_on_cloud` and the `share_link_file` services).

We highlighted this situation because in points like this the system is able to generate different behaviors for addressing the same goals. Configurations capture this kind of variability that is fundamental to customize the final system.

For instance, the self-configuration phase for the running example results in three different configurations, each of them resolving the order management process by employing a different set of capabilities. These are extracted as subset of the reported graph and listed below.

```
Configuration1
    to_wait_order <-- !wait_order,
                      !retrieve_user_data
    to_notify_invoice <-- !check_storehouse,
                          !generate_invoice,
                          !upload_on_cloud
    to_deliver_order <-- !notify_storehouse_manager
    to_notify_failure <-- !notify_stock_failure

Configuration2
    to_wait_order <-- !wait_order,
                      !retrieve_user_data,
                      !send_reg_form,
                      !wait_user_data
    to_notify_invoice <-- !check_storehouse,
                          !generate_invoice,
                          !upload_on_cloud
    to_deliver_order <-- !notify_storehouse_manager
    to_notify_failure <-- !notify_stock_failure


Configuration3
    to_wait_order <-- !wait_order,
                      !retrieve_user_data
    to_notify_invoice <-- !check_storehouse,
                          !generate_invoice,
                          !upload_on_cloud,
                          !share_file_link
    to_deliver_order <-- !notify_storehouse_manager
    to_notify_failure <-- !notify_stock_failure
```

## IV. The Proposed Model for Self-Configuration

This section illustrates an approach to domain-independent self-configuration of cloud applications. Self-configuration is intended as the ability to automatically aggregate and configure a set of services thus to ensure the correct global functioning with respect to defined user's goals [10].

### *A. A Three-Layered Architecture for Self-Configuration*

The proposed approach is structured in three inter-operating functional layers: the goal layer, the capability layer and the service layer.

The uppermost layer of this architecture is the ***Goal Layer*** in which the user may specify the expected behavior of the system in terms of high-level goals. Goals are not hard-coded in a static goal-model defined at design time. The goal injection phase allows the introduction of user-goals defined at run-time. Goals are interpreted and analyzed and therefore trigger the need of the system to generate a new configuration.

The second layer is the ***Capability Layer***, based on solving at run-time the problem of Proactive Means-End Reasoning [11]. It aims at selecting the capabilities (and configuring them) as a response to requests defined at the top layer. This corresponds to a strategic deliberation phase in which decisions are made according to the (often incomplete) system knowledge about the environment. The output is the selection of a set of capabilities that will form a correct and effective business process. This is obtained by instantiating system capabilities into business task and associating capability parameters with data objects. In this phase the procedure also specifies dependencies among tasks and how data items are connected to task input/output ports.

The third layer is the ***Service Layer***, it manages and interconnects autonomous blocks of computation thus generating a seamless integration for addressing the desired result specified at the first layer. Section VI describes the run-time orchestrator that executes the business process generated at the second layer by interacting with the corresponding cloud applications and web-services.

### *B. Implementing the Cloud Capabilities*

The aforementioned high-level architecture is actually deployed though a distributed system of software entities namely ***Cloud Capabilities***.

Whereas traditionally services and cloud applications are passive entities that act when receive the control [7], [12], cloud capabilities are lively cloud applications (running at SaaS) inspired to the principles of autonomic computing. Each cloud capability keeps its own control, it is able of sensing the surrounding environment, making proactive decisions, and interacting with other capabilities for organizing a common behavior [11], [13].

From the developer's point of view, a cloud capability is a facilitator for quickly implementing cloud applications with high level features such as autonomy, proactiveness, self-organization and logic reasoning. In a mashup, a capability acts as a stateful wrapper for a specific web service or a cloud application.

We implement a cloud capability through two components as shown in Figure 5: a general-purpose reusable core and a service customized part. The core provides a generic set of APIs to support the three-layered architecture shown in the previous section:

- Goal Management: some facilitators to handle the interpretation of single goals in GoalSPEC and to manage the whole goal-set;
- a Self-Configuration module that exploits a logic-based reasoner (to handle the matching between goals and capabilities) and some self-organization protocols (to collaboratively generate configurations);
- an Adaptive Orchestrator responsible of translating a configuration into an operative plan and to enact the corresponding workflow in a dynamic environment.

The customizable part of a capability allows to set up the generic 'core' for working with a specific service (either web-

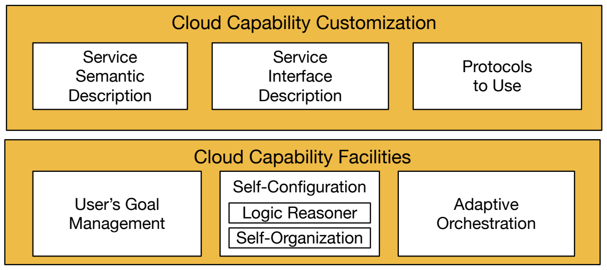

Cloud Capability Customization
Service Semantic Description
Service Interface Description
Protocols to Use
Cloud Capability Facilities
User's Goal Management
Self-Configuration
Logic Reasoner
Self-Organization
Adaptive Orchestration

Fig. 5. Internal Architecture of a Cloud Capability.

service or cloud application). The *Service Interface Description* allows to specify how to manage the service wrapping (service input/output ports), including how to maintain a state for the correct functioning of stateful services. The *Protocol to Use* (HTTP/ HTTPS/ SOAP ...) may be selected among pre-defined ones, even if new ones may be programmed from scratch to occurrence. Finally, the *Service Semantic Description* allows to specify information related to the self-configuration phase such as pre/post conditions and evolution (as described in Section II).

For instance, *UploadOnCloudStorage* is a wrapper for a generic REST file storage service on the cloud (`upload_on_cloud(file,user_account)`) that requires defined parameters and produces a remote clone of a local file by returning a unique id that identifies that remote object. The following first-order predicate represent the *cloud capability customization* part for the aforementioned capability.

```
capability(upload_on_cloud_storage,

  % semantic description
  precondition(available(document)),
  postcondition(uploaded_on_cloud(document)),
  evolution(add(uploaded_on_cloud(document))),

  % service interface
  method(https,put),
  address(https://content.dropboxapi.com/1/files_put/
       auto/),
  input([
         param(local_file,file),
         param(remote_file_path,rxfile)]),
  output([param(metadata,json_file_descriptor)]),

  % protocols
  service_protocol(rest),
  require_auth(oauth20)
).
```

The first compartment (*semantic description*) contains exactly information already discussed in Section III-B: pre/post conditions and evolution. The second compartment (*service interface*) specifies which method to use for the service invocation, the address for reaching the service and any input/output ports to provide for a correct invocation. Finally the latter compartment (*protocols*) indicates that the service call must follow the REST protocol and the consequent request should be signed (it requires a preliminary OAuth authentication).

## V. Self-Configuring a Mashup

This section focuses on the central layer of the presented architecture, and in particular on the strategy adopted for automatically establishing run-time links between user's goals and the available capabilities. Please, refer to [9] and [13] for more details about GoalSPEC (goal layer) and self-adaptation (service layer), respectively.

Here the problem is, for each goal $g_i$, to discover which sequence of capabilities may be employed for satisfying Equation 2.

In other words, invoking a single service produces changes in the state of the world that are specified in the corresponding capability's property *evolution*. This describes the expected changes in terms of *add* and *delete* operators that respectively add new statements to the state of the world, or delete existing statements, for producing the resulting state.

Consequently, executing a sequence of capabilities produces a multi-step evolution of the state of the world i.e $e = \{W_1, W_2, \ldots, W_n\}$. Such evolution $e$ satisfies a goal when the goals' trigger condition is satisfied in $W_{k1} \in e$, and the final state eventually holds later in some subsequent state: $W_{k2} \in e : k2 \geqslant k1$.

### A. The Proposed Strategy for Self-Configuration

The possible evolution paths of a system are modeled as a state transition system (Figure 4) where nodes are states of the world and transitions are due to the execution of capabilities. We refer to this structure with the name of world transition system (WTS, hereafter). The WTS is built with the contribution of a subset of the available cloud capabilities.

The WTS is implemented as a blackboard cloud service, i.e. accessible by all the capabilities, so that every cloud capability may add new nodes and transitions in a collaborative fashion. However, in order to avoid the concurrent modification of the same WTS, cloud capabilities enforce a blind auction protocol [14] for deciding the priority of write access, as described herein.

The blackboard service allows users to register a new goal-set. When this happens it creates a new shared WTS that only contains the initial state of the world node. Subsequently it starts a cycle of auctions, playing the role of auctioneer, and it periodically sends a call-for-bids to any potentially interested capability.

At the same time, each cloud capability starts an *expand-and-evaluate* cycle, working on the portion of WTS already available. They concurrently produce new states and transitions that are privately stored. These new states are evaluated with respect to the goals, according to a global scoring function. This is used for predicting how much the new state is promising with respect to the goal-set.

Periodically, when a new call-for-bid incomes, each cloud capability selects the most promising state it has generated during past expand-and-evaluate iterations. The state score is used for setting a bid for participating to the auction. Who wins the auction gains the permission to update the WTS.

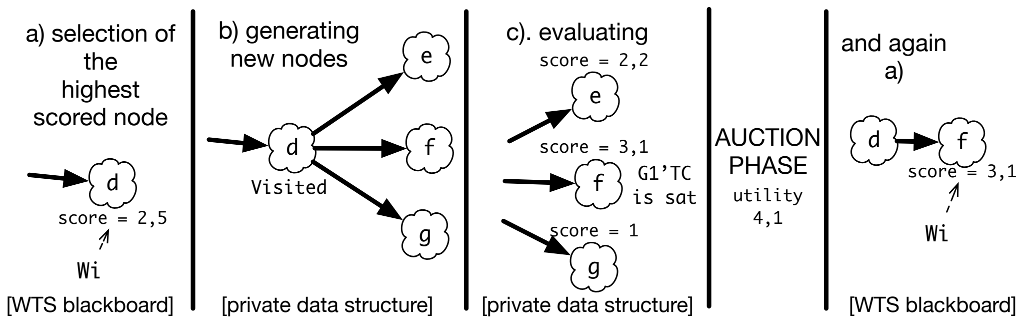


Fig. 6. Steps of the Expand and Evaluate Strategy.

This strategy rewards those capabilities that promise to improve the WTS by increasing the global goal satisfaction.

## B. The Expand-and-Evaluate Cycle

When a user specifies a goal-set to address, cloud capabilities enters in an expand-and-evaluate cycle, working with the WTS in read-only access. The cycle is described in the following.

1) The capability selects those nodes of the WTS that satisfy its pre-conditions;
2) The capability picks the most promising node, among the selected ones (Figure 6.a);
3) The capability simulates the effects of its wrapped service by generating new states through the evolution property (Figure 6.b).
4) The capability generates a score for each new node and stores them in a private data structure. The more the state of the world is close to addressing some goals, the higher is the score assigned to it (Figure 6.c); a node is also marked as $TC\_holds_i$ or $FS\_holds_i$ if the node satisfies respectively the triggering condition $TC_i$ or the final state $FS_i$ of the goal $g_i$.

## C. The Global Scoring Function

The aim of the scoring function is to predict how much a state of the world is *near* to the final state where a goal is satisfied. The principle is that a state of the world is described by a set of numerable statements. We defined a function that evaluates the potential impact of each of these statements for addressing a goal. To the aim of producing a quantitative measurement, the function rewards statements that provide a positive impact to a goal and it penalizes statements that do not provide a positive impact to a goal.

The function is defined as follows:

$$score(W) = \sum_{g_i} \frac{1 + num\_rel\_stats(W, g_i)}{num\_stats(W)} \tag{3}$$

where, given a state $W$, $num\_rel\_stats(W, g_i)$ is defined as the number of statements contained in $W \cap (TC_g \cup FS_{g_i})$, whereas $num\_stats(W)$ is the cardinality of $W$, i.e. the number of statements contained in $W$. For instance, if $W = \{s_1, s_2, s_3, s_4, s_5\}$ and $g = \langle s_2 \wedge s_8, s_4 \vee s_5 \rangle$ then $num\_stats = 5$ and $num\_rel\_stats = 3$ because $\{s_2, s_4, s_5\}$ are relevant for $g$.

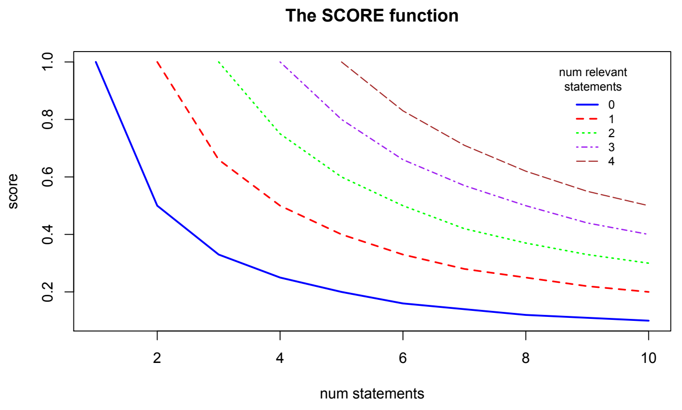


Fig. 7. Line chart of the score function highlights trends of the value when making either $num\_stats(W)$ or $num\_rel\_stats(W, g)$ constant.

Figure 7 illustrates Function 3 plotted as a stacked line chart for highlighting the score trends. Setting to constant the $num\_stats$ in the formula, the score is higher the more the statements are relevant for the goal satisfaction. Conversely, making the $num\_rel\_stats$ constant, the score increases when the total number of statements in $W$ decreases.

This may be interpreted as follows: a state is interesting if it promises to quickly converge to exactly the desired final state. Clearly the prediction based on this heuristic is not guaranteed to be neither optimal or perfect, but empirically it revealed sufficient for the specific purpose of speeding the exploration of the graph.

## D. The Auction Cycle

The auctioneer launches a new blind auction with a constant time interval. The auction starts when a call-for-bid is sent to the capabilities. They have a fixed deadline to reply with a bid.

Each participant selects the node –from its private expand list– with the highest utility, calculated as follows: the node's score plus the number of TC_holds and FS_holds for that state.

The highest utility is the bid to send back to the auctioneer (see Figure 6).

There is not counter-offer, the auction closes when all capabilities replied or at a predefined deadline. The capability with the highest bid wins the auction and therefore it updates the WTS consequently. In practice, it copies the selected node from its private data structure to the global WTS, also reporting eventual transitions with pre-existent nodes. For instance, Figure 6 shows that the new node $f$ is connected with its predecessor $d$ from which it originated.

The procedure cycles again with a new auction until a *MAX* number of configurations is discovered or if the auctioneer receives only empty offers for a number of times (expanding the WTS is no more possible).

Figure 8 reports an example of WTS generated for the fashion firm running example where these conditions hold:

$TC_1(W_1) = true$
$FS_1(W_2) = true$
$FS_1(W_3) \wedge TC_2(W_3) = true$
$FS_1(W_4) \wedge TC_2(W_4) = true$
$FS_1(W_5) \wedge TC_2(W_4) = true$
$FS_1(W_6) \wedge TC_4(W_6) = true$
$FS_1(W_7) \wedge FS_4(W_7) = true$
$FS_1(W_8) \wedge TC_4(W_8) = true$
$FS_1(W_9) \wedge FS_2(W_9) \wedge TC_3(W_9) = true$
$FS_1(W_{10}) \wedge TC_4(W_{10}) = true$
$FS_1(W_{11}) \wedge FS_2(W_{11}) \wedge FS_3(W_{11}) = true$

The final phase is the extraction of configurations from the final WTS. A configuration associates each goal of the goal-set to a simple or composed capability.

The procedure we report searches for paths between states where $TC_i$ holds and states where $FS_i$ holds, for each goal $g_i$. Since graph transitions are associated to capabilities, a path represents a simple or composed capability for addressing $g_i$. Therefore, the resulting capability is obtained by aggregating the capabilities corresponding to the transitions of the discovered path. In the example, a path is detected for the goal [to_notify_invoice]. In Figure 8 this path –from $TC_2$ to $FS_2$– is highlighted with a thicker line and the corresponding capabilities are annotated. Consequently the composition *CheckStorehouse*, *GenerateInvoice* and *UploadOnCloudStorage* represents a solution for the goal [to_notify_invoice].

The whole set of configurations is obtained as a combination of the capabilities discovered for each goal. The configurations for the FashionFirm running example are shown in Figure 9. The proposed approach has been also employed in the EtnaValley project[4].

## VI. From Configuration to Mashup

This section describes how a configuration, extracted from the WTS, is transformed in an effective workflow in order to operationalize the cloud application mashup.

The transformation follows two principles:

[4]Another example of cloud application mashup involving different capabilities may be found at http://ecos.pa.icar.cnr.it/etnavalley.

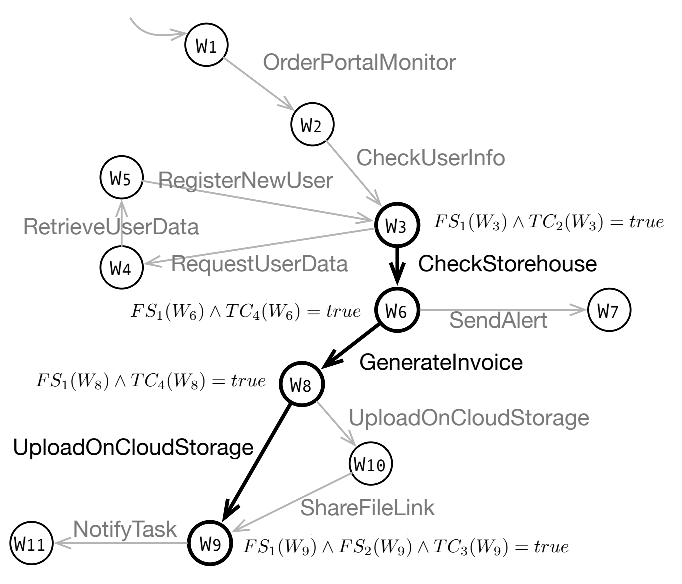


Fig. 8. Example of navigation of the WTS for identifying goal-satisfaction. Transitions are annotates with the corresponding capability responsible of adding the arc. A thicker line highlights a path for goal $g_2$ that corresponds to [to_notify_invoice] in the FashionFirm running example. Thicker nodes are annotated with the logic expressions that are true in the corresponding state of world (from $W_1$ to $W_{11}$). $TC_i$ and $FS_i$ respectively denote the triggering condition and final state of the goal $g_i$. So, for instance, the final state of $g_1$ and the trigger condition of $g4$ are satisfied in $W_8$.

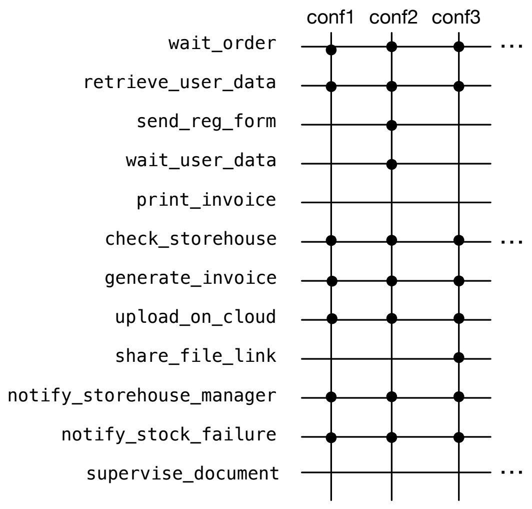


Fig. 9. Example of set of configurations.

- *Principle 1: Dynamic Association between Capability and Goals.* Each capability – selected for addressing a goal – will be executed according to the lifecycle represented in Figure 10.
- *Principle 2: Distributed Control.* All the capabilities act autonomously (in parallel) and interact to the aim of coordinating their behavior. Interactions are driven by the current state of the world and by the need of exchanging some data objects.

The Principle 1 arises from the fact that each capability

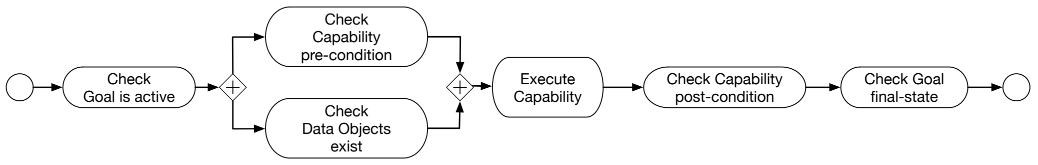


Fig. 10. Flow of activities corresponding to the execution schema related to a generic association (goal,capability).

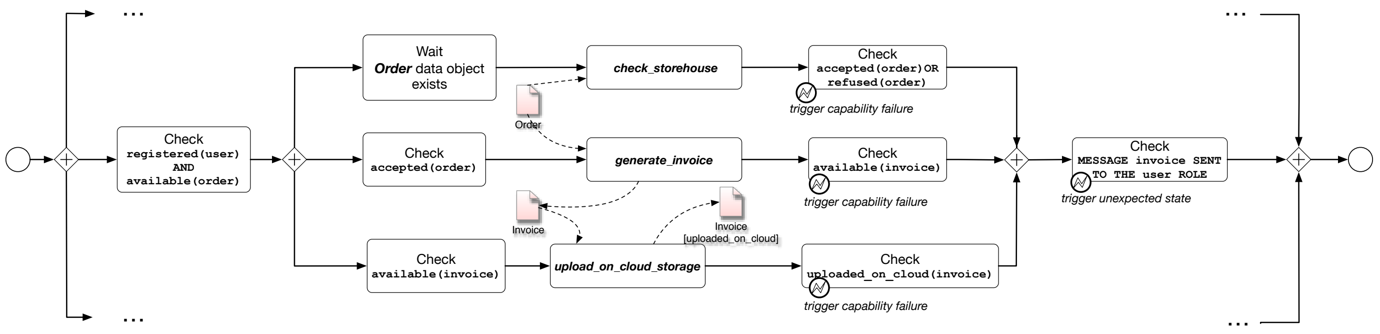

Check registered(user) AND available(order)
Wait Order data object exists
check_storehouse
Check accepted(order) OR refused(order)
trigger capability failure
Order
Check accepted(order)
generate_invoice
Check available(invoice)
trigger capability failure
Invoice
Invoice [uploaded_on_cloud]
Check available(invoice)
upload_on_cloud_storage
Check uploaded_on_cloud(invoice)
trigger capability failure
Check MESSAGE invoice SENT TO THE user ROLE
trigger unexpected state

Fig. 11. Overview of the resulting workflow equivalent to a full-parallel execution model. Each branch of the workflow corresponds to a capability. It is built by instantiating and optimizing the lifecycle presented in Figure 10 with specific goal and capability properties.

contributes to address one of the goals. A triggering-condition (TC) is associated to each goal and specifies when the goal becomes ready. This is the first condition that must hold for executing the related service. However, the capability also requires a pre-condition must hold. At the same way, the post-condition reveals the success or failure of the service. Finally, the goal's final state (FS) asserts when the goal has been successfully addressed. Figure 10 summarizes a schema of the typical flow of activities associated to a generic capability.

When several capabilities are requested for addressing the goal-set then all the capability functional schemes must be merged.

Principle 2 states schemes must be combined though a parallel gateway (see Figure 11) thus generating a workflow in which each branch represents a different service (Figure 10). Different branches interact by two different synchronization approaches. *Implicit mode*: a branch waits until a condition of the state of the world is true. This state is generally generated as the final state of a prior service of the workflow. This model is implemented by means of a shared blackboard that stores the current state of the world. *Explicit mode*: a branch requires to process some data object that is produced as output by another branch. In this case a Query Interaction protocol [15] is employed to enable the direct exchange of data.

Figure 11 reports an exemplar slice of the workflow (using the BPMN 2.0 notation) obtained by applying the two transformation principles to the configuration 1 (shown in Figure 9). We highlight the branches corresponding the [to_notify_invoice] goal that involves three capabilities: *CheckStorehouse*, *GenerateInvoice* and *UploadOnCloudStorage*. The first condition $available(order) \wedge available(user)$ is the same for the three branches because it is the goal's triggering condition. For the sake of clarity the workflow has been simplified to avoid duplicate activities, as shown in Figure 11.

Therefore, when an order has been received from a registered user, the workflow waits for three possible events: i) an order data object to be processed, ii) a notification that the order has been accepted, or iii) an invoice to deliver. These are the entry points for the branches corresponding to the three capabilities that execute `check_storehouse`, `generate_invoice` and `upload_on_cloud_storage` respectively.

For example, after `check_storehouse` service is executed, the capability's post-condition and the goal's final state are checked. An example of explicit synchronization happens between the second and the third branches: the invoice data object is produced by the *GenerateInvoice* and consumed by the *UploadOnCloudStorage*.

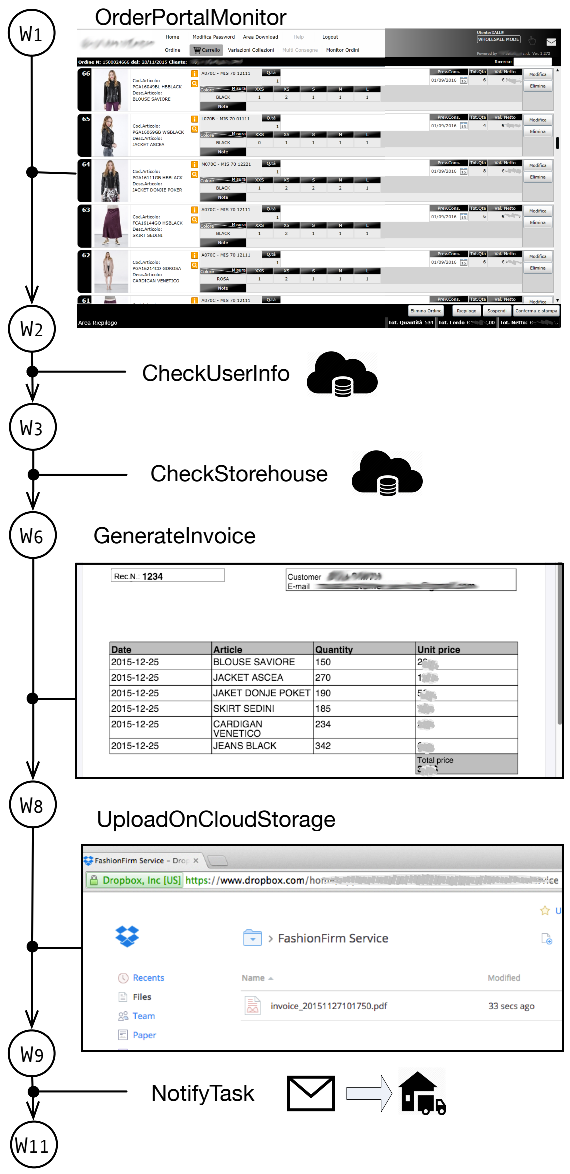
Figure 12 reports the aforementioned scenario of execution with some screenshots concerning the front-end parts of the exploited capabilities.

## VII. Related Work

The current state of the art in cloud computing delineates *mashup* as an innovative technology for the integration of cloud applications [2], [16], [17]. Compared to traditional 'developer-centric' composition technologies, mashup is inspired to principles of flexibility and user-friendliness.

OpenCloudware [18] and FIWARE [19] represent a couple of worldwide initiatives that have began implementing this vision through a backend infrastructure.

OpenCloudware [18] is a project coordinated by France Telecom Orange. It aims at building an open software engi-



Rec.N.: 1234

Customer [redacted]
E-mail [redacted]

| Date | Article | Quantity | Unit price |
|---|---|---|---|
| 2015-12-25 | BLOUSE SAVIORE | 150 | [redacted] |
| 2015-12-25 | JACKET ASCEA | 270 | [redacted] |
| 2015-12-25 | JAKET DONJE POKET | 190 | [redacted] |
| 2015-12-25 | SKIRT SEDINI | 185 | [redacted] |
| 2015-12-25 | CARDIGAN VENETICO | 234 | [redacted] |
| 2015-12-25 | JEANS BLACK | 342 | [redacted] |
| | | | Total price [redacted] |

FashionFirm Service – Drop
Dropbox, Inc [US] https://www.dropbox.com/hom[redacted]vice

› FashionFirm Service

| Name | Modified |
|---|---|
| invoice_20151127101750.pdf | 33 secs ago |

Fig. 12. Execution of a scenario for the fashion firm running example. Some screenshots of the cloud application mashup have been attached to the capabilities of configuration 1.

neering platform (PaaS) for the collaborative development of distributed applications to be deployed on multiple cloud infrastructures (IaaS). OpenCloudware support mashup through a set of tools to manage the lifecycle of such applications from many point of views: modelling, developing, deployment and orchestration.

Conversely, FIWARE is an open architecture and a reference implementation of a service infrastructure [19] whose mission is: “to build an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards that will ease the development of new Smart Applications (SaaS) in multiple sectors”. It offers an application mashup platform allowing end users without programming skills to easily create web applications by manually integrating heterogeneous data, application logic, and UI components sourced from the Web.

Our approach for self-configuring mashups provides an alternative vision respect to the classic workflow model definition. It aims at decoupling the technical skills for developing a service from the analytic skill of describing mashup compositions.

Helin and Laukkanen [20] present an approach for composing worflows that is based on semantic type matching. As well as our approach, authors highlight the importance of ontology for creating semantically annotated services. The main difference is that their approach mainly automatizes finding and matching semantically similar web services, whereas the composition still requires the human intervention during the composition process.

In [21] authors model web service composition as a planning problem and use non-deterministic transition systems where composition is achieved by model checking. Despite there exist similarities with our work, their strategy for building the transition system is not specifically suitable for running in a distributed fashion, requirement that is necessary in the Cloud environment.

Another related work is Colombo [22] a framework for automatic web service composition that exploits relational database schema, atomic processes, message passing and a finite state transition system. As well as our approach, they introduce the goal service, i.e. they make explicit that a composite service is aggregated for addressing a goal. The main difference is that in Colombo a service goal is directly represented as a transition system, that demands a user to learn very technical skills.

In [16] authors explicitly focus on the composition of cloud components and highlight the need for self-controlled service components. They adopt a MAPE-K loop [23] to provide autonomic behavior at component level. However the composition is still modeled at design-time by developers.

## VIII. Conclusions

In this paper, we describe our approach to the development of Cloud Application Mashup. This approach has been exploited in the context of a research project whose some characteristics have been presented as running example.

Our approach is based on the decoupling of what to do from how to do it. To this aim we used a three levels architecture where the user specify his problem and automatic tools build the resulting application.

On the developer side, services must be encapsulated within Cloud Capabilities, lively and autonomous SaaS applications that provide reasoning and composition facilities.

On the final-user side, she has to define the business logic of the mashup in the form of goal-set as GoalSPEC specifications. There is indeed the need of some minimal skill in order to specify the problem to be resolved. Goals must be specified adopting some ontological formality and conflict-free. In order to reduce the complexity of this work, off-line tools – such as that presented in [24] – may help the user in defining his desired application.

Service providers could have their own goals too. We are still working at integrating a third component close to goals and capabilities: norms. Norms are rules that must hold during all the phases of self-configuration but also during service orchestration and execution. To date this is yet an ongoing work.

When both capabilities and goals are specified, then we can build a new mashup application just composing available cloud applications or web services exploiting the proactive characteristic of cloud capabilities as long as these exist in the repository. Capabilities can be figured out as proactive entities that bind an abstract description of some action to a real web service or cloud application. The main feature of cloud capabilities is to be 'social' i.e. able to interact in order to generate a shared solution to the set of user's goals.

The novelty of our approach lies in the fact that the user does not need to know how his mashup application will be composed or which components will be assembled. Each capability corresponds to specialized web services or cloud applications. Furthermore, redundant capabilities can make the resulting application safe from any service failure.

All these features are implemented in a middleware [13] that offers a whole architecture for monitoring goal injections, self-configuring ad-hoc solutions and finally to orchestrate Cloud components. The approach is not tied to a specific application domain. Indeed the specification of a domain ontology is a fundamental step for customizing the middleware for the specific working context. Examples of different customizations can be found in the website[5]. To date the middleware has been adopted for implementing a document sharing solution, a cloud mashup platform (the running example reported in this paper), a risk management system and a smart travel agency.

## IX. Acknowledgment

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