Human-Computing Grids

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ABSTRACT

In this paper, we present the idea of human-computing grids - a unified, generic approach in treating of human and computing resources. Human-computing grids are aimed at creation of solutions that can better merge human and machine intelligence and create something bigger than itself. The basic idea of our approach is to create architecture that enables a synergic use of human and computer resources based on the principles of how grid computing integrates computing resources. Treating these different domains in a unified way can introduce some new ideas and lead toward novel solutions.

Categories and Subject Descriptors

C.2.6 [**Internetworking**]: Standards, H.5.3 [**Group and Organization Interfaces**]: Collaborative computing, J.4 **[Social and Behavioral Sciences**]: Sociology.

General Terms

Management, Measurement, Design, Economics, Human Factors, Theory.

Keywords

Computing grids, social computing, computer-supported collaborative work.

1. INTRODUCTION

Interned enabled almost unlimited possibilities for connecting computers and people. Many online projects have been started, and many new forms of distributed computing have appeared. Among them, grid computing is currently one of the most prominent areas [1]. Although developed in relatively independent domains, grid computing and many of the human collaborative online activities have much in common. In order to support various applications and serve different users, grid computing coordinates different computing resources that are not subject to centralized control. On the other hand, many collaborative human activities, such as the open-source movement, basically follow the main ideas of grid computing, coordinating work of people that are also not subject to centralized control. Noticing these similarities, and having in mind the growing interest and support for grid computing, the following question naturally arises: Can we reuse grid architecture and extend it to support more efficient integration of human and machine intelligence?

In this paper, we present the idea of human-computing grids - a unified, generic approach in treating of human and computing resources. Human-computing grids are aimed at creation of solutions that can better merge human and machine intelligence and create something bigger than itself. As Patie Maes once noted, now when we have the Internet, we have a specific mix of humans and machines that behaves as that we have a sophisticated intelligent machine [2]. For example, we can send a message to mailing lists and get the answer to many questions, or even get people to do something for us. The basic idea of our approach is to create architecture that enables a synergic use of human and computer resources based on the principles of how grid computing integrates computing resources. Treating these different domains in a unified way can introduce some new ideas and lead toward novel solutions.

In next section we briefly discuss grid computing and human collaborative activities. Then, we describe the proposed approach toward creating unified human-computing grids, where we present the semantic framework and architecture of human-computing grids. After that, we illustrate our approach on several novel types of applications. In the end, we give short discussion and conclusions.

2. GRID COMPUTING AND HUMAN COLLABORATIVE ACTIVITIES

In this section, we shortly describe grid computing and human collaborative activities, discussing similarities between these two areas.

2.1 Grid Computing

Grid computing has attracted lots of attention in recent time. Presently, it is the area of intense activity of a large community of researchers, developers, and users. Numerous experimental and production grids are in operation all over the world. Similarly to the World Wide Web, grid computing started as a technology for scientific collaboration but was later adopted by a large number of industries and businesses. Recent standards activities driven by the Global Grid Forum (GGF) have led to the definition of the Open Grid Services Architecture (OGSA), which has met with wide acceptance and is being implemented in commercial grid products [3]. Precise definition of grid computing is still discussable. However, useful staring point is Ian Foster definition of computing grid as a system that [4]:

1) Coordinates resources that are not subject to centralized control,
2) Use standard, open, general-purpose protocols and interfaces, and
3) Deliver nontrivial qualities of service.

Grid computing is primarily concerned with coordinated sharing of resource in dynamic, multi-institutional virtual organizations. One of the key problems that grid computing addresses, is the ability to negotiate resource-sharing arrangements among providers and consumers and then to use the resulting resource pool for some purpose. There are many applications based on grid computing principles. Scientists and engineers have used computing grids for years, and millions of desktop PCs run a grid application behind a popular screen saver. For example, SETI, the Search for Extraterrestrial Intelligence (http://setiathome. ssl.berkeley.edu), uses a huge number of computers connected to the Internet which download and analyze radio telescope data, and upload the results during their idle times. SETI had scavenged over almost two million years of CPU time, linking about five million users from over 200 countries. Some enterprises also use a grid computing, to make use of their desktop PCs to prepare monthly customer billing statements after business hours. Some other enterprises analyze individual financial portfolios and investment strategies in a similar way. In these applications, grid middleware starts the jobs, leads them to the idle PCs for processing, catches the errors and exceptions, redirects and restarts lost jobs, collects results, and distribute the results [1].

Table 1. Examples of some types of human collaborative online activities.

Project type	Participants	Human resources	Outcome	Comm. mechanism	Example URL
Open-source projects	Programmers	Programming skills	Code	Web applications	**Apache Foundation** http://www.apache.org **Linux** http://www.linux.org
Peer reviewing	Experts in the field	Expertise in some area, constructive criticism	Recommendation, textual comments	Web applications Email	**IEEE Manuscript central** http://cs-ieee.manuscript central.com/
Distributed proofreaders	Ordinary users	Reading, attention, editing skills	Corrected text	Web applications	**Distributed Proofreaders** http://www.pgdp.net/
Encyclopedia writing	Ordinary users	Knowledge, reading, editing skills	New text, correction of existing materials	Web application	**Wikipedia, the free encyclopedia** http://www.wikipedia.org/

2.2 Human Collaborative Online Activities

The Internet has enabled broad cooperation of different individuals from all over the world. Besides enabling better and richer communication, it introduced many new types of working and collaboration, not present in the real world. The most characteristic example is the open-source movement. As noted by Robert Glass, people build software for no pay, and argue that everyone else should do the same, making this movement as one of the most fascinating subjects of our time [5]. But there are many other activities based on the similar principles. Table 1 presents some of these online activities, describing them in terms of who participates, what they do, e.g. what resource they offer, what the main outcome of each participant is, and what communication mechanism is used.

What is particularly interesting is that many of these collaborative online activities can be described with Foster's definition for grid computing, as they:

1) Coordinates people (human resources) that are not subject to centralized control. People involved in enlisted activities are not doing it as a part of their regular job; they do it in their free time, and voluntarily. More precisely, participants appear as complex resources, as they offer their skills and their computing resources, but participants, not the centralized system, control the use of these computing resources, so computing resources cannot be used independently.
2) Use standard, open, general-purpose protocols and interfaces. Communication is usualy made using some widely available Internet service, such as email, or some Web based open-source system, such as the Concurrent Versions System (CVS).
3) Deliver nontrivial qualities of service. Many results are comparable with results from industry leaders. Examples include the Apache projects (see http://www.apache.org) and Linux.

So, having in mind these similarities, we wanted to explore if it is possible to reuse grid architecture and extend it to support integration of human and machine intelligence. To contrast other researchers who have been analyzing high-level aspects of incorporating human aspects into grid computing for collaborative work [6], we wanted to create a flexible framework for interaction of human and machine intelligence on various levels o abstraction, such as at perceptual, cognitive or social level.

3. HUMAN-COMPUTING GRIDS

The basic idea of our approach is to create architecture that can enable a synergic use of human and computer resources based on the ideas of how grid computing integrates computing resources. We propose a unified, generic approach leading toward creation of solutions that merge human intelligence and machine intelligence and create something bigger than itself. In order to go toward creating unified human-computing grids, we have done the following:

- Defined a conceptual framework for human-computing grids,
- Defined generic architecture for human computer grid applications, and
- Discussed novel applications based on the proposed ideas.

3.1 A Conceptual Framework for Human-Computing Grids

In order to formally describe the semantics of the basic human-computing grids concepts, we have firstly defined the metamodel where we gave a generic, unified view on synergic use of human and computing resources. This metamodel also defines a vocabulary of modeling primitives for description of human-computing grids and applications. For example, based on this metamodel, we have developed several modeling extensions, including Unified Modeling Language (UML) extensions, in order to describe some of existing and new human-computing grid applications.

The main concept of our metamodel is a grid resource. Figure 1 shows a simplified definition of grid resources, based on the composite software designed pattern. A grid resource can be simple or complex. A complex grid resource integrates various simple or complex grid resources, while a simple grid resource represents an atomic resource. We defined computing and human types of a simple grid resource. Computing resources are classified in computing cycles, storage, network bandwidth, and software resources. These are generic classes that further can be classified in more concrete categories. Human resources are classified as perceptual, cognitive, social, and mobility. Human perceptual resources describe human ability to perceive complex phenomena, such as patterns, three-dimensional layout, or motion. Cognitive resources describe higher-level mental functions, and are further classified in knowledge resources, reasoning and skills. Social resources describe human ability to work and collaborate with other people, such as managerial skills. Mobility describes the ability of humans to move around, which can have valuable applications in applications such as distributed sensing.

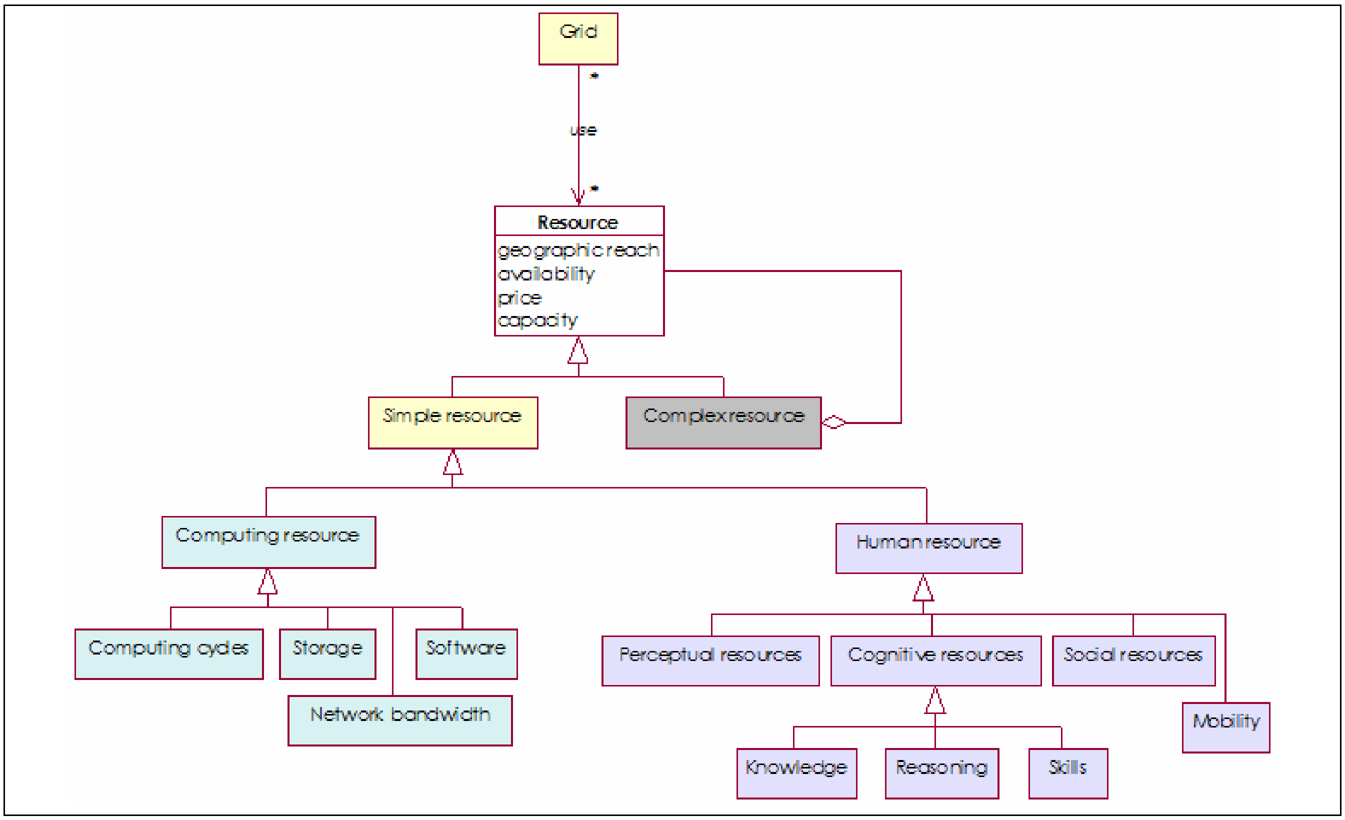

Figure 1. Metamodel of computing and human resources used in grids.

Figure 1 presents how some of the existing activities, such as peer-reviewing and distributed proofreading can be described with UML extensions defined according to our metamodel [7]. For example, a peer reviewing is a human computing grid that usually integrates several peer reviews, the editor and some computing resources, such as manuscript database, specially dedicated to reviewing (Figure 2a). Communication between the reviewers, editor and the systems is usually made by email. A peer reviewer is modeled as a complex grid resource, integrating the person that actually performs the reviewing, and reviewer computing resources, e.g. his or her computer and software. It is important that each reviewer has enough computing resources and appropriate software for viewing and editing. Among the things that are crucial for the reviewer are expertise in the area, and ability to provide constructive criticism. Editor inherits the qualities of a peer reviewer, adding two important social components: visibility and authority in the field, as well as acquaintance of experts.

In similar way we can describe distributed proofreading (Figure 2a). Distributed proofreading can be described as a human-computing grid integrating computing resources specially dedicated for this purpose, and many distributed proofreaders. A distributed proofreader is a complex grid resource, integrating a reader, his reading skills, vocabulary and editing skills, and his computing resources necessary for performing the job.

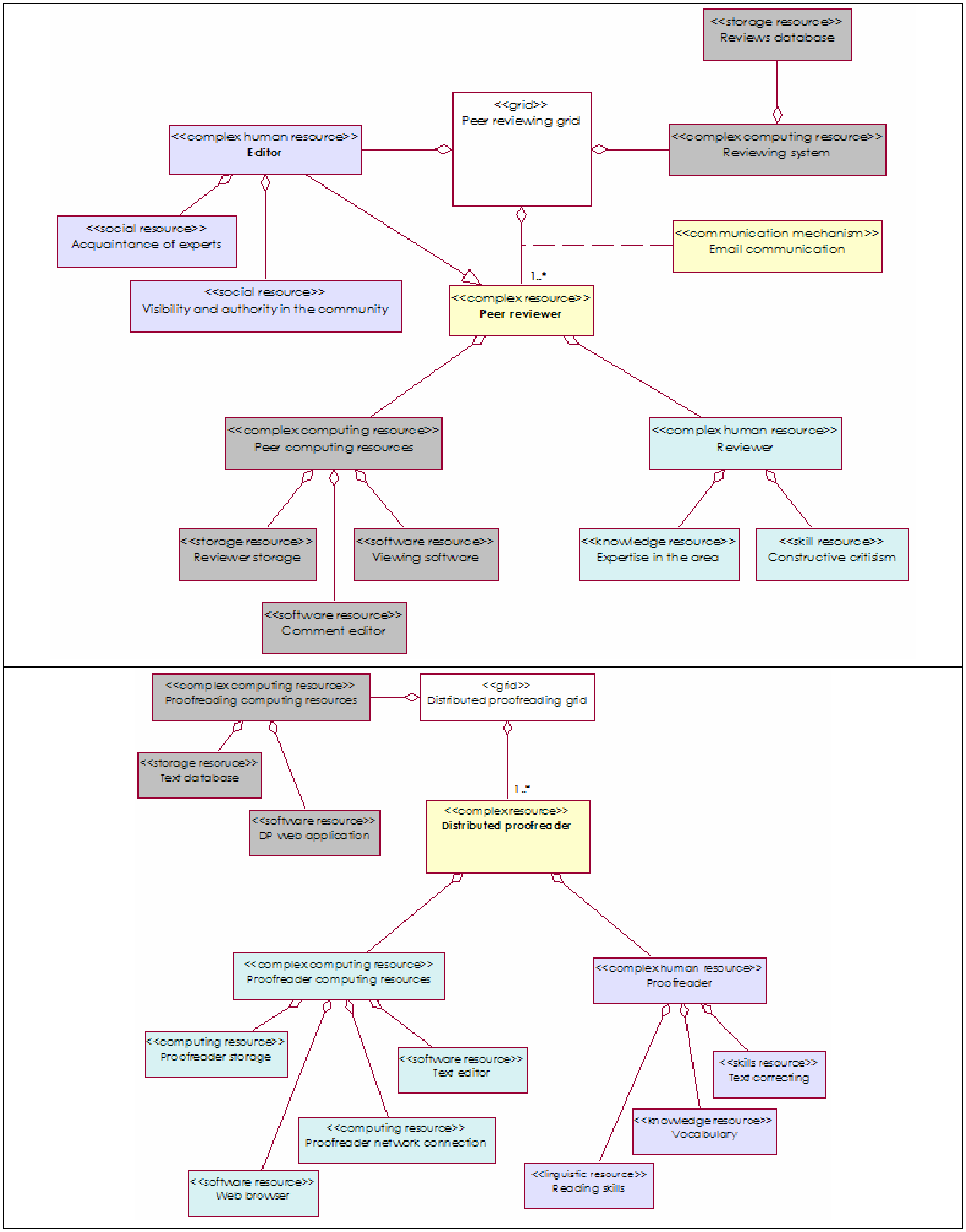

Figure 2. UML models of peer reviewing (a) and distributed proofreaders (b).

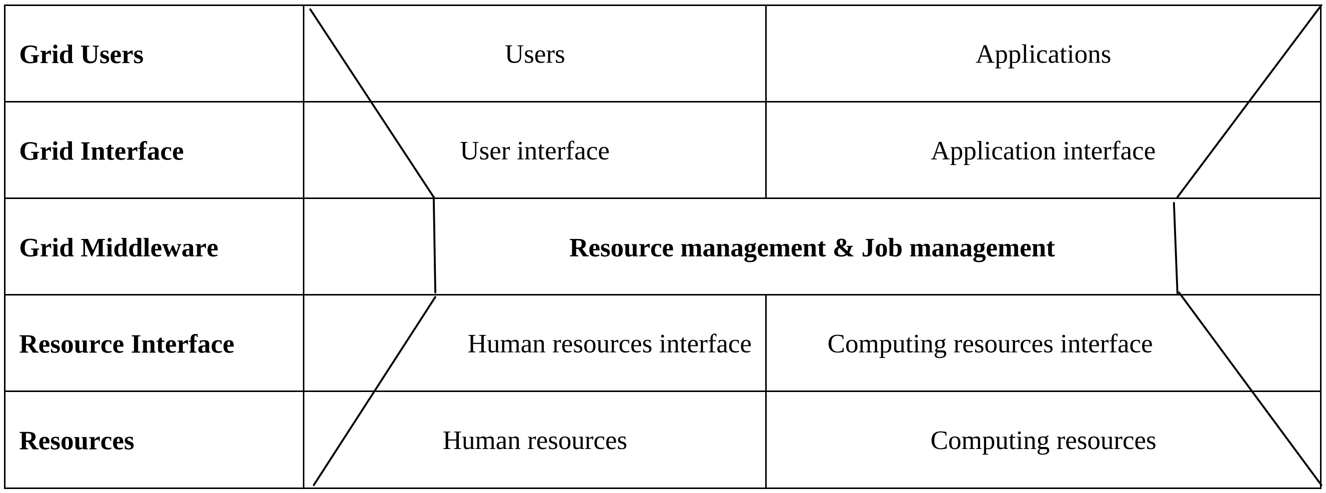

Figure 3. Human-computing grid architectural components.

3.2 Generic application architecture

Examples in the previous section have illustrated how human and computing resources can be described in the same way. However, the real improvements could be achieved only if we could create application architecture components, which would enable more efficient integration of human and machine intelligence.

Using typical grid computing architecture [1] as a starting point, we have introduced several extensions in order to enable integration of human resources. As a result, proposed human-computing grid architecture in total must be capable of performing high-level functions and services presented at the Figure 3. At the highest level in our architecture are the grid users. Some grid can be used by various users, or it can be integrated in other grids and applications. Next level is the grid interface, which provides the users with access to services such as signing-on, authentication, access management, coordination of access rights and privileges, exchange of credentials and certificates, and asserts trust relationships.

On the lowest level, we have human and computing resources, and appropriate interfaces for usage of these resources.

The middle level - grid middleware has the key role in connecting users and resources. It generally provides following two groups of services:

- Resource management, and
- Job management.

Table 2 shows high-level functions and services of grid middleware, describing what service it provides and what is specific for usage of human resources.

Compared with computing only grids, key challenge of human-computing grid middleware is dividing a job in tasks so that a human can finish it in limited time, and that results can be collected seamlessly. Other challenge is estimating the quality and efficiency of human resources. While it is much easier to quantify and evaluate computing resources, human resources need more elaborate description. It is also essential to classify user according to their expertise, for example, as beginners, normal users, experts and "gurus".

3.3 Discussion: Human-Computing Grids and Pervasive Computing

Human computer grids do not need any new implementation technology. Internet provides us with rich communication infrastructure, while various standards, such as various XML based standards, give as a reach open environment for development of various applications.

More importantly, increasing numbers of users are nowadays surrounded by multiple ubiquitous computing devices. As our devices connect to a global wireless network, we become members of a 24-hour global society—one where we are always connected, and always on [8]. Personal digital assistants (PDAs) such as the 3Com PalmPilot and personal organizers such as the Sharp Wizard are already popular, while digital cell phones are merging with digital pagers and PDAs to form portable, wireless communication devices that support voice, along with electronic mail, and personal information such as schedules and contact lists. Therefore, we have powerful information infrastructure which can be used for various human-computing grid applications.

Table 2. High-level functions and services of grid middleware, with specific for human resources.

Components		Description	Specifics for human resources
Resource management	**Discovery**	Locate a needed resource.	May require periodical check to see if the user will be available in some period. This is also a practice in many human activities. For example, when preparing the final manuscript of the paper scheduled for publication, editors often introduce sentences such as "Please let me know if you will be unavailable during the next four weeks".
	Advertising and registration	Resources joining or leaving the pool.	In some cases may involve evaluation of users, or require certification. For example, some internationally recognized language diploma.
	Resource attributes and characteristics	Configuration, availability, cost, usage policy, and constraints.	Could be based on user self-evaluation, on some tests, on recommendation, or on the certificate.
	State	Operational status and load.	What the user is doing, how loaded is he/she. When will he/she be available for the next task?
	Provisioning	Identifies and locates resources that are appropriate for jobs and tasks, and negotiates and authorizes their use. The application might make these decisions based on resource characteristics, service quality, availability, state, location (for delay-sensitive applications), and cost.	Should include additional statements about cancelation policy.
	Data management	Reliable and secure communications (mechanisms and protocols), and directory services via third-party transfers.	User should be educated how to work so not to compromise the data they are working on.
Job management	**Initiation**	The user or application submits one more jobs. The application might also schedule jobs in advance.	The user should acknowledge the acceptance of some job, and be reminded for the deadlines, such in publication procedures.
	Scheduling	Dispatch jobs and tasks, and coordinate grid chores that are not subject to centralized control. Schedulers are hierarchical. Schedulers also arbitrate conflicts arising from contention for the same resource.	The user could give periods when he is willing to work on something, and how fast can he/she finish average jobs. This could be based on the test results, and on previous results and reliability. The user should also have the possibility to choose among given jobs.
	Monitoring	Grids require the monitoring and control of jobs and resource assignments. Monitoring mechanisms trap, log, and diagnose errors and exceptions.	The user may be requested to estimate the progress, and to provide partial results, and reminded about the deadlines.
	Completion	As tasks and jobs finish, completion mechanisms assemble and distribute results (from various sites), and release resources.	It should also integrate results of various individual working on the same problem.
	Accounting	If a grid must purchase resources, it will require accounting and billing mechanisms.	It is essential to classify user according to their expertise, for example, as beginners, normal users, and experts.

4. SOME NOVEL APPLICATIONS

In this section we present some of ideas for projects for applying ideas of human-computing grids. We wanted to focus on tasks that are very simple for humans, and very complex for computers (Table 3). For example, people have sophisticated and stabile shape recognition abilities, outperforming computers in many ways. This ease of human shape recognition, contrasted with high complexity of computer-based shape recognition, is exploited as the only viable protection against mass automated registration on free sites, such as Yahoo Mail. These sites are asking the user to type text awkwardly displayed in a figure. People recognize text without much trouble, which is almost impossible task for current computing techniques.

Table 3. Humans vs. Computers.

Humans are good at:	**Computers are good at:**
Sensing low level stimuli, Recognizing patterns, Reasoning inductively, Communicating with multiple channels, Apply multiple strategies, and Adapting to changes or unexpected events.	Sensing stimuli outside human's range, Calculating quickly and accurately, Storing large quantities and recall accurately, Responding rapidly and consistently, Performing repetitive actions reliably, and Working under heavy load for an extended period.

We will describe several projects, such as marking points of photographs, digitalizing photographs, rhythm indexing, metadescription of photographs, distributed translations, distributed sensing of weather and traffic conditions, digitalizing photographs, rhythm indexing, distributed brainstorming, and new forms of eLearning. *The main strenght of these applications is in their ability to meaninglessly collect small increments of many users.* Table 4 give comparative descriptions of these applications, describing which human resources it uses, what is a basic production unit, and what is the estimated time that each person should spend to produce a production unit. In following section, we will describe each of these applications.

4.1 Metadescription of photographs

In this project we addressed the problem of adding metadata to some of historical pictures. Humans are superior to computers in perceiving complex images, especially real world images such as photographs. Indexing and searching of images is a rather complex problem, and most of existing computing solutions search images according to file name, and sometimes according to their position in source document [9]. However, without appropriate metadata, search engines are not able to make complex analysis.

Table 4. Some novel applications.

New application	**Human resources used**	**Production unit**	**Estimated time per person**
Metadescription of photographs	Visual pattern recognition, perception of 3D cues, general knowledge	Text (paragraph) describing content of the figure.	10^{2} seconds
Marking points of photographs, digitalizing photographs	Visual pattern recognition	Index points on the figures	10^{2} seconds
Distributed translations	Language knowledge, translating skills, editing skills	Translated text (pages)	10^{3} seconds
Distributed sensing of weather and traffic conditions	Mobility, perception of weather and traffic conditions	Answers according to predefined criteria	10^{1} seconds
Rhythm indexing	Audio pattern recognition	Beats as a function of time	10^{2} seconds
Distributed brainstorming	Imagination	Few sentences of text.	10^{2} seconds
New forms of eLearning	General knowledge, specialized knowledge, pedagogical skills	Description, textual or oral, about some topic	10^{2} seconds

Recognizing shapes, places, and humans on photographs could enable complex searches, and could be a valuable source for many users. The basic idea of out project is to make use of human visual perception to add such metadata to images. With many users online, where each user adds a few sentences about what it perceives or recognizes on figures, it is possible to create critical amount of data for searching images according to various criteria.

Ideas proposed in this project could also be useful for indexing images other than historical. People are often willing to donate little of their time, especially if they are using some valuable service for free sites. Many free mail sites sometimes ask their users to participate in various surveys of other companies. In similar way, users could be asked to index images, and they could offer this as a service to other companies.

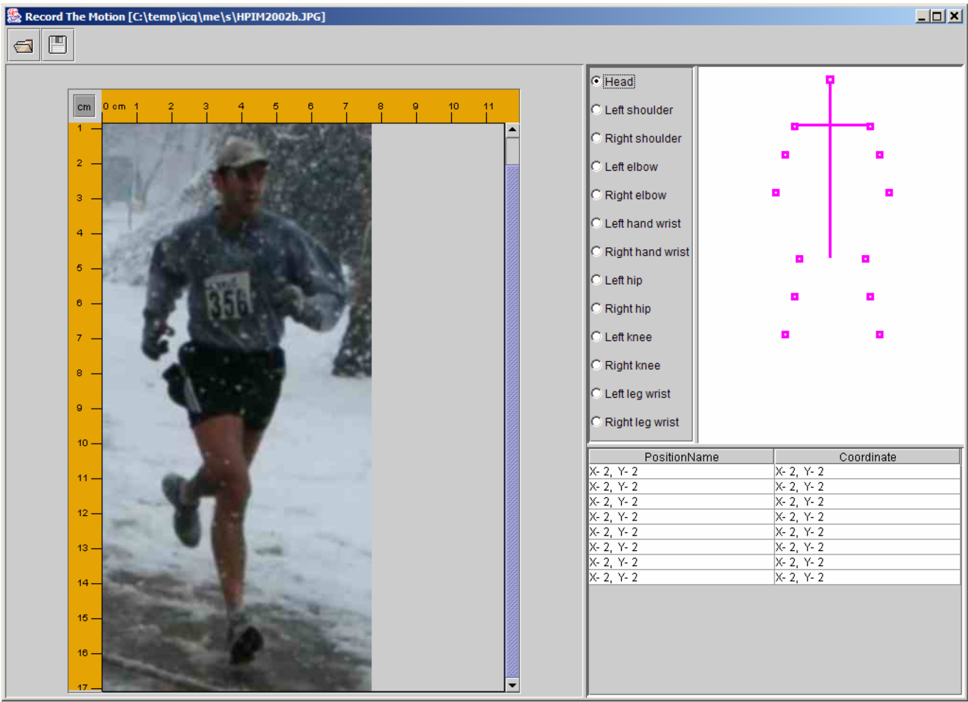

Figure 4. User interface for marking points of photographs, and manual digitalizing of photographs.

4.2 Marking points of photographs, digitalizing photographs

Digitizing human motions and body positions, is important for many applications. Such as medical applications that measure joint position in kids, or digitalizing dancing movements. Many motion tracking systems have been proposed and implemented. However, most of them require that users wear special sensors or visual markers, and they require many cameras in specialized conditions. This is another hard problem for computers, especially if dancers do not wear any special equipments or markers. Even then it sometimes requires up to ten cameras and sophisticated offline processing.

However, many applications cannot afford special equipment and cameras. Again, user pattern recognition, and their ability to easily recognize three dimensional objects from two dimensional photos, can be very helpful here. Figure 4 shows a user interface of a simple applet that enables users to mark joints of the person on the. Each user index a limited set of joints, not the whole body. As subsequent pictures often differ just a little, additional help for users is introduced so that the next figure have preset index points from the previous figure, and user just has to correct it a little. It is also possible to ask to user to digitalize each n^{th} photograph, and then interpolate positions in between, and ask the user to check if the interpolation is correct.

4.3 Distributed translations

Translating foreign text is another application where humans are still much better that computing system. Hence, many companies have professional translators, who are working on translations of documents of their foreign partners. However, having a few translators can be a bottleneck, and hiring additional ones can be a problem especially if you have to translate the text quickly. On the other hand, many people have the knowledge of other languages, and can be used for some short translations.

The basic idea of our project is to enable collaborative translation of text by engaging more translators who would translate some smaller amount of text, such as few pages. In this way, it is possible to get quick translations, at reasonably price. It is even possible to engage translators who are working on other bigger projects, as they could spend small amount of time on this job. Of course, the style of the document would not be consistent, but sometimes, especially in technical materials, this could be satisfactory, or additional editor may be hired to make the style consistent. When registering as distributed translators, people could prove theirs skills by some language diploma, or by translating some sample text.

4.4 Distributed sensing of weather and traffic conditions

People are all around the world, and they often move around. Today many of them use various pervasive devices, thus representing a powerful distributed sensing platform. The basic idea of this project is to enable distributed sensing of weather and traffic conditions based on the location of the users. Many areas are not covered with cameras and other sensors, but there is always someone "on the road". Communication can be based on simple protocols, such as SMS messages, where a user could send a simple answer according to discrete set of weather and traffic conditions. Perception of these conditions is trivial for people, but having this data can be really helpful in many situations. Many radio stations already use similar mechanism, receiving data from taxi drivers, and their listeners.

4.5 Rhythm indexing

Many people are quite good in recognizing the rhythm in songs. Although there are systems that can track rhythm in songs, rhythm tracking for all kinds of music is not always a practical solution. Again, many people can do this task without much effort. Having discrete markers of rhythm can be helpful for animation of characters, and for synchronization with other media, such as the video sequence of the dancing, or animated characters.

4.6 Distributed brainstorming

In this project, we wanted to explore usage of human imagination and humans' ability to apply multiple strategies in solving different problems. People have two roles: *idea generators*, and *idea evaluators*. Idea generators reply with a few sentences on question about some problems, while idea evaluators gave their opinion about concrete idea, for example, classifying it as interesting, not interesting, did not understand, and so on. The same person can sometimes have both of the roles.

4.7 New forms of eLearning

Currently, in eLearning humans are used to create learning objects which are then used by students. In human-computing grids they could be learning objects themselves. The basic idea of this project is to extend the conventional discussion lists so that users could register their knowledge, and then be contacted by other user who needs help. Moreover, through interaction between the users, it is possible to create learning objects implicitly, for example by recording it. This way of learning is valuable not just for academic education, but also for various everyday things such as legal advices, advices about buying things, and so on.

5. DISCUSSION AND CONCLUSIONS

In this paper, we have presented the idea of human-computing grids - a unified, generic approach in treating of grid computing and human collaborative online activities, aimed at creation of solutions that can better merge human and machine intelligence and create something bigger than itself.

We have noted that one of the main challenges of human-computing grids is dividing a job in tasks so that a human can finish it in little time, and that results can be collected seamlessly. Other challenges include estimating the quality and efficiency of human resources. While it is much easier to quantify and evaluate computing resources, human resources need more elaborate description. To make a different from current part-time arrangements, human-computing grids can also be very short-lasting, sometime just for a few seconds or minutes.

Human-computing grids could lead also toward new types of working, where people could register the resources they are willing to give, such as knowledge or skills, and be used and paid in an *ad hoc* style.

In our future work, we plan to work on agent-based platform for implementation of human-computing grids. We think that an agent based system is natural paradigm for implementation of human-computer grids. For example, each use could have its personal agent that represent the user and made some sort of negotiation, perhaps they could prepare working environment for the user getting some material for the user, for example search the Internet for data about the subject.

In the end, we shortly discuss some newly open problems, such as implicit and explicit activities in human-computing grids, as well as the role which grids can have in revitalization of retired persons.

5.1 Implicit and explicit activities in human-computing grids

Currently, most of human collaborative activities are explicitly oriented on the task of the project, e.g. people do what they are requested to do, and they would not do it otherwise. However, interesting and important topic of our future research are implicit activities: people do what they would have done anyway, but their results and knowledge is shared with the others. For example, when you are buying a car you have to ask lots of questions, and find best price according to multiple criteria. Once you have finished the buying, you have very valuable knowledge which you do not need any more, but currently you do not have the means to efficiently share it with other people who are in a similar situation. Here, we are working on ideas similar to new forms of eLearning, where people could register and share their knowledge.

5.2 Revitalization of Retired persons

Governments in many countries invest lots of efforts in creating various programs to help retied and elderly find work, volunteer programs, and be active part of their communities. Many of retired citizens are willing to participate in various activities, often of their own accord. American Association of Retired Persons (see http://www.aarp.org), The U.S. Administration on Aging (see http://www.aoa.gov)

Human-computing grids could enable them to donate their time and resources to work on projects. As grids are opportunistic, and jobs usually require little time and efforts, retired and elderly person could be an important part of many human-computing grids.

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