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Web-based Human- and Machine-Driven computation

Tesi di laurea specialistica



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La citazione è un utile sostituto dell'arguzia.

— Oscar Wilde

Dedicato a tutti gli appassionati di \LaTeX .

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ABSTRACT

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*Abbiamo visto che la programmazione è un'arte,
perché richiede conoscenza, applicazione, abilità e ingegno,
ma soprattutto per la bellezza degli oggetti che produce.*

— Donald Ervin Knuth

RINGRAZIAMENTI

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Como, Settembre 2012

L. P.

INTRODUCTION

In the field of distributed computing have been used several methods to create a common layer able to execute code on different systems and platforms. The paradigm of distributed computing is based on the paradigm of grid computing and on that of cloud computing. These paradigms leverage on the core concept of creating an abstraction layer on top of the available resource in order to make them consistent, for example grid computing abstract only part of the available resources, meanwhile cloud computing abstract the whole hardware.

The distribution of the computation can be done at **hardware** or **software** level.

At **hardware** level we have similar distributed resources, or at least can be easily abstracted, so we can distribute and gather the results. This paradigm is used in frameworks like [Dean and Ghemawat, 2008](#) where the computation is spread on large cluster of computers.

The distribution of computation at **software** level uses the concept of distributed systems, where the automatic computation is spread among different machines usually separated by a network. Once the computation is executed by a node, the result is processed by the server and if needed another computation is triggered by ther server, an so on.

Another paradigm has been outlined in this field, **human computation**. The paradigm is the same as above because we need to computation but here the nodes have the ability to perform computation that other standard nodes, like pc and similar, are not able to do.

As one may notice, the idea of human computation is very similar to distributed computation also it leverage on web-based distribution technologies. Users get engaged using the web, and also the tasks are executed within a web browser. Human computation application or [GWAP](#) usually relies on the web as a common platform like [Von Ahn, Liu, and Blum, 2006](#) or [MTurk](#). Another solution is to create a standalone normalized software platform like [FoldIt](#).

Given this general overview one can spot that we reached a condition where we have the technical ability to use all the web-users as nodes able to perform arbitrarily complex computation either automatic or human.

As far as we know there are no methods or tools able to stress this opportunities, because they focus on human or automatic computation¹. The matrix in table 1 is the representation of the available online tools categorized using as dimensions the will of the user of perform-

¹ Not web-based, but using standalone clients.

ing such tasks and the *complexity* of the algorithm. When using the term *complexity* we refer to two main types of computational complexity *workload complexity* and *algorithm complexity*.

Workload complexity indexes all that algorithms that need to perform a huge amount of simple (or not so simple) computation on a lot of data. To address this problem we need use the *Divide et impera* paradigm, like the one used in [Dean and Ghemawat, 2008](#), allowing to split algorithms that operates on huge amount of data into atomic steps that can be executed by any node. When dealing with this type of complexity we need to do **automatic** computation.

Algorithm complexity addresses the other dimension, here we consider the complexity as the computational feasibility of each step of the algorithm. As an example consider the following algorithm:

```

input : a set of tweet about a politician
output: each tweet marked as in favor or against the politician

foreach tweet in tweets do
  opinion  $\leftarrow$  check(tweet);
  if opinion  $\neq$  IN_FAVOR then
    | contactCIA();
  end
  setTweet(tweet, opinion);
end

```

Algorithm 1: Tweet validation

The algorithm itself is not complex but operation like $\text{opinion} \neq \text{IN_FAVOR}$ cannot be done by a normal node, like a pc, or they took too long to be computed. These cases belongs to the field of **human** computation.

Table 1.: Task distribution and execution matrix.

| | Automatic | Human |
|-------------|-----------------------|-----------------------|
| Voluntary | BOINC | MTurk |
| Involuntary | Parasitic computing | GWAP |

A limitation of the available frameworks for automatic computation is the ease of access of the tool for the end-users. Let's take Search for Extra-Terrestrial Intelligence *at* home ([SETI@home](#)) as an example, this tool uses the Berkeley Open Infrastructure for Network Computing ([BOINC](#)) platform to search for extraterrestrial activity using radio telescope and analyzing narrow-bandwidth radio signal. A user who want to participate to this project must install the [BOINC](#) platform and then enter a specific URL to start contributing. This steps, despite their simplicity, have hidden overhead to the user and to the [SETI@home](#) project. The installation of ad-hoc clients can be a problem when a user work on a machine with strong restriction, also the [SETI@home](#)

project must adapt their data and computation to be executed within the [BOINC](#) platform.

ORIGINAL CONTRIBUTION

The aim of this thesis is to present a model for distributing and executing task that covers all the matrix dimension expressed in table [1](#), and on top of that provide:

- ease of access to the tasks
- usage of standardized protocols/languages
- ease of implementation by the *requester*
- ease of execution by the users

The original contributions are:

1. Definition of a model for automatic, human and hybrid computation
2. Implementation of a reference web-based architecture for human and automatic implementation
3. Implementation of an infrastructure supporting the defined model
4. Validation through 3 use cases ([automatic](#), [human](#), [hybrid](#))

OUTLINE

The thesis is organized in four main parts.

[THE FIRST CHAPTER](#)

[NEL SECONDO CAPITOLO](#)

[NEL TERZO CAPITOLO](#)

[NELL'ULTIMO CAPITOLO](#)

1

THE BACKGROUND

Recent years have seen an increasing interest in *Human Computation* and *Crowdsourcing* areas. One of the reason they are becoming so attractive is the growth of the Web. This has allowed to leverage the ability of people over the internet to perform tasks that even modern computers cannot achieve properly.

This chapter, first, focus on the key steps and developments in these fields that lead to the purposes of this thesis. We provide an overview of [human computation](#) and parasitic computing, then we introduce the technologies that enables the distributed computation on the web such as [HTML5](#) for the task distribution and execution and [WebCL](#) for the task execution.

1.1 CROWD-BASED COMPUTATION DISTRIBUTION

Distributing computation (task computation) in the crowd means splitting the task execution into atomic subtask that can be executed by a host (human or not).

Write something about the crowd based distribution of the tasks, use references to (Mechanical turk [Little et al., 2010](#)) if possible.

The online tool [MTurk](#) provide a framework for the creation distribution, execution and result gathering of task (called Human Intelligent Task ([HIT](#))). Diring the creation a *Requester* The *Requester* can push request for executing [HIT](#), these are

1.1.1 Human computation & [GWAP](#)

Computers are capable of performing many tasks, they can process large amounts of data and do billions of operation in a few seconds. However, there are still many problems that computers cannot solve or take too much time to solve even for the powerful pc.

Some of this are very simple tasks for humans, for example natural language processing and object regonition are hard to solve problem for a computer but natural for a human being, A great example for this kind of problem is recognizing hand-written text, even after years of research, humans are still faster and more accurate than ony computer.

Furthermore, there are problems that are too computationally expensive, such as many NP-complete problems like Traveling Salesman problem, scheduling problems, packing problems, and FPGA routing problems.

The expression *Human Computation* in the context of computer science is already used by [Turing, 1950](#). However is [Law and Ahn, 2011](#) to introduce the modern usage of the term. He defines human computation as a research area of computer science that aims to build systems allowing massive collaboration between humans and computers to solve problems that could be impossible for either to solve alone. But, in my opinion simple and direct definitions are better to get the point:

*Some problems are hard, even for the most
sophisticated AI algorithms.
Let humans solve it. . .*
— Edith Law

Centralized

Centralized Mturk

Distributed

Distributed FoldIt

1.1.2 Automatic computation

Voluntary computing

BOIC + SETI

Parasitic computing

Parasitic computing¹ is a technique that, using some exploits and ad-hoc code, permits to execute computation on unaware host computer. This approach was first proposed by [Barabási et al., 2001](#) to solve the NP-complete 3-SAT problem using the existing TCP/IP protocol and its error handling routines.

Parassitic compiting has a strong relationship with *distributed computing*, in fact it is like a specialization of the general class of *distributed computing* where the user is unaware of the execution². Given that we can list the main steps used to perform distributed computing:

- Split task into atomic operations executable by any host
- Send the code to all the host computers
- Execute the code
- Gather the results from the hosts

¹ In this thesis we are not covering, neither we are interested, in the ethical or moral implication of using such programming model.

² In *distributed computing* the user can be unaware of the purpose computation is for or what actual code they are executing, but they are aware of the execution.

- Join all the hosts result and compute the task output

Distributed computing leverage on the idea of *divide and conquer* like the programming model of MapReduce³. Frameworks as [BOINC](#) and [SETI@home](#) implement distributed computing paradigm to perform large scale operations (such as signal analysis) among the volunteers that installed the clients. These volunteers choose the project they are interested in and give the idle time of their machines to perform the computation.

Parasitic computing performs the same kind of task in the same *distributed* fashion but the main difference is that the users are unaware of the computation that is being executed on their pc.

- **Parlare di quante volte effettuiamo computazione parassitica senza sperlo.**
Esempi?
- **Parasitic computing può anche essere fatto in un modo conscio.**
Notificando all'utente la possibilità di eseguire del codice (senza sapere quale) in cambio di un ritorno di qualche tipo ([Karamé, Francillon, and Čapkun, 2011](#)).
- Using the same model of unaware host we can perform high level computation using JavaScript.[Modernizr](#)

The main drawback of distributed computing is the portability and distribution. The installation of some kind of client to execute the code can be seen as a problem for some user, as an example some users simply cannot install software on their workstation, due to security restriction or missing disk space. The other problem is distribution, the main purpose of these frameworks is to perform massive parallel computation, but for the computation to be really massive we need a lot of volunteers that installed the client on their pc and are online to execute the code.

Grafico con insiemi per distributed computing and parasitic computing?

`PARASITIC JAVASCRIPT` can lead to a solution of these problems using a widespread and standard technologies. Using the Web as the distribution platform the audience can scale rapidly from to thousands to hundred thousands of users. Regarding the need of third part software installation and security issues, using JavaScript these problems are avoided, because all the code the browsers runs is executed into a sandboxed execution environment so it cannot harm the users pc. The same stands for the portability of the code, because almost all browsers⁴ support JavaScript with all the HTML5 features (see [1.2.1](#)), so the porting of the code is guaranteed on every system that can run a browser.

³ [Dean and Ghemawat, 2008](#).

⁴ `**COUGH** IE **COUGH**`

Let make an example **CREARE ESEMPIO CON BOINC E UN SITO DA 500.000 VISITE**

Using parasitic JavaScript can lead to some **hybrid** solution between distributed and parasitic computing. Using the browser we can ask to user if it is willing to run some code ⁵ then we can proceed downloading all the required resource to run the code. This approach make possible to have a proactive approach to volunteer computing, so there is no more the need of waiting until the users are willing to spend some time running a task.

This **hybrid** approach is proposed in [Karame, Francillon, and Čapkun, 2011](#) as long as a μ Payment model for task execution.

- problema del distributed computing (installazione del client | distribuzione) - FATTO
- soluzione: piattaforma standard condivisa da tutti Javascript - FATTO
- problema HTML4 -> HTML5 collegamento - FATTO
- permette una soluzione idriba (avviso che può essere eseguita della computazione, l'utente sceglie) - FATTO

1.2 ENABLING WEB-BASED DISTRIBUTED COMPUTATION

Web-based computation implies that a client is able to perform almost any kind of task that usually is done by an application software, as an example think about image analysis, audio/video playback or socket connection; these operations are available to developers without the need of additional libraries or external *plugins*.

When building Rich Internet Application ([RIA](#)) developers have to face the problem of building *rich* web application without the required tools for **communication**, **data access** and **data storage**. Access to raw data of images or audio, API for file management, data storage and full-duplex communication are all problems that could not be solved without using plugins like Flash or Silverlight.

The advent of HTML5 has brought a breath of fresh air to the Web. HTML5 specifies all these features as part of the language specifications so they are being implemented in all major javascript engines (Presto, V8, SquirrelFish, JägerMonkey). This means that almost all the required tools to build real *rich* internet application are built-in in the JavaScript language.

COMMUNICATION is being empowered by the introduction of *WebSocket* that enable full-duplex data exchange with the server. Also the introduction of Cross-origin Resource Sharing ([CORS](#)) give the

⁵ mettere una nota in cui si parla del revenue dell'utente e alla sezione in cui viene discusso meglio il tutto

developers the possibility to contact foreign servers using Asynchronous JavaScript and XML ([AJAX](#)) without the need of a proxy for forwarding the requests.

DATA ACCESS is obtained using HTML5 media elements (`<video>` and `<audio>`) or the File API.

DATA STORAGE is available through the `localStorage` and `sessionStorage` global variables or using IndexedDB or even a built-in WebSQL database.

With the introduction of all these features developers can use the power of JavaScript to perform image analysis, audio/video playback (without any external plugin installed), create 2D/3D games and so on.

These features make possible to create tools like *Emscripten* that is a LLVM-to-JavaScript compiler. Basically allow developers to convert their C/C++ code into standard JavaScript, obviously the performance are not comparable but different level of code optimization lead to good performance gains in terms of code size and execution speed.

Additionally specification like [CORS](#), not strictly related to JavaScript, allow the users to make cross-site request, that was a great limitation in JavaScript development.

1.2.1 HTML5

In this thesis when i refer to HTML5 i'm not speaking only about the HTML5 tag reference. I am speaking about a set of technologies and specifications related to HTML5. It includes the HyperText Markup Language version 5 ([HTML5](#)) specification itself, the Cascading Style Sheets ([CSS3](#)) recommendations and a whole new set of JavaScript APIs. So, first things first, lets make some clarification:

HTML5 refers to a new set of semantic tag (like `<footer>`, `<header>`, `<article>`, ...), media tags (like `<video>` or `<audio>`) and the so called Web Form 2.0.

CSS3 refers to the presentation layer specification including image effects, 3D transformation, tag selectors and form element validation.

JS refers to the new set of API provided, that enable interaction with all these new elements, and additional, non tag-related, functionalities (like WebSockets or WebWorkers).

With the advent of [HTML5](#), like any new web-technology, many problems were resolved and many others have been created. The main issue with using HTML5 is the browser compatibility and browser-specific methods. Every browser has its own implementation of the HTML5, this is mainly due to the early implementation of draft specification⁶.

⁶ In fact HTML5 (at the time of writing) is not yet standardized, is still a draft. See <http://www.w3.org/TR/html5/>

To avoid browser inconsistency we could use JavaScript frameworks. Frameworks like *jQuery* provide a layer of abstraction between browser-specific code and the user, giving developers JavaScript fallbacks for the most common API and additional features not covered by the standard implementation. Other tools like *Modernizr* give developers the ability to test if some HTML5 features are supported or not and provide a general fallback system for dynamically loading polyfills⁷.

Now i will analyze in detail the main features of HTML5 to better understand their usefulness.

CANVAS Let's start with the official definition⁸

The canvas element provides scripts with a resolution-dependent bitmap canvas, which can be used for rendering graphs, game graphics, or other visual images on the fly.

So basically is a *Canvas*, like the name says, but give the developer the access to the raw pixel data of the canvas contents. Also in the canvas element you can draw the image taken from an `` tag or a frame from a `<video>` tag. As you can see now we have the capability to manage image data directly and perform client-side task like image analysis or video manipulation. Obviously there are plenty of JavaScript libraries that give you methods to perform image filtering or generally image manipulation (like *Pixastic* or *Camanjs*), other libraries give you the possibility to create images on the fly (like *Raphaël* or *Processingjs*).

The canvas element also provide a 3D context to draw and animate⁹ high definition graphics and models using the WebGL API. This API is maintained by the *Khronos Group* and is based on OpenGL ES 2.0 specifications. On top of these API there are a lot of libraries¹⁰ created for easy development, the most used is the *Three* JavaScript library, that can be used for creating and animating 2D or 3D scenes in the canvas element.

WEBSOCKET The WebSocket is an API interface for enabling bi-directional full-duplex server communication on top of the Transmission Control Protocol (TCP) protocol. The WebSocket enables the clients to create a communication channel between the server and the client, allowing the server to push data to the clients and obtain *real* real-time content updates.

Like other HTML5 features, WebSocket has a library, build on top of the API, that provides easy access to these functionality as long as a couple of fallbacks. *socket* provide a single entry-point to create a

⁷ A polyfill is a JavaScript library or third part plugin that emulates one or more HTML5 features, providing websites to have the same *look and feel* also on older browser.

⁸ Got from the specs: <http://www.w3.org/TR/html5/the-canvas-element.html#the-canvas-element>

⁹ Animation is not natively supported, you must code it yourself.

¹⁰ For a reference see http://en.wikipedia.org/wiki/WebGL#Developer_libraries

connection to the server and manage the message exchange, it also provide a few fallbacks¹¹ to ensure cross-browser compatibility.

WEBWORKERS A problem you have to face when you are building computationally heavy JavaScript code is its single thread nature. Every script runs in the same thread, this can lead to some unwanted behaviour like browser freezing or the newly introduced warning dialog "*A script is slowing the browser*". The browser shows the dialog to prevent freezing or crashing of the whole browser application, but this dialog prevent the script to fulfill their task. So how can we execute long running JavaScript computation if the browser stop the code?

Jenkin, 2008 proposed a timed-based programming structure that ensure the code to be run without any browser warning and also offer the developer to tweak the performance of the script by dynamically adjusting the interval between the step execution. This method leverage on the `setTimeout` function of javascript in order to split code into timestep-driven code chunks to execute. Here is an example of loop translated into a time-based loop:

```
while condition do
| ...do something...
end
```

```
procedure STEP
| ...do something...
| if condition then
| | setTimeout(STEP,
| | delay)
| end
```

Obviously this is not a solution it is a way to hack the browser JavaScript performance monitor and avoid the warning dialog. WebWorkers provide a standard way to create *Workers* that execute in background, also performing heavy computation without harming the browser flow. Let's provide an official definition:

The WebWorkers specification defines an API for running scripts in the background independently of any user interface scripts. This allows for long-running scripts that are not interrupted by scripts that respond to clicks or other user interactions, and allows long tasks to be executed without yielding to keep the page responsive.

So basically fills the gap of parallel code execution in JavaScript.

1.2.2 WebCL

With the advent of General-purpose computing on graphics processing units (**GPGPU**), the spreading of multicore CPUs and multiprocessor programming (like OpenMP) we can see emerging an inter-

¹¹ WebSocket, Adobe® Flash® Socket, AJAX long polling, AJAX multipart streaming, Forever Iframe, JSONP Polling

section in parallel computing. This intersection is known as **heterogeneous computing**. Open Computing Language ([OpenCL](#)) is a framework for heterogeneous compute resources and so Web Computing Language ([WebCL](#)) is a porting of this technology to the web.

[OpenCL](#) uses a language based on C99¹² for writing *kernels*, functions that actually execute on OpenCL devices.

The main focus when building high-end web-application like 3D games is responsiveness. Although JavaScript can be optimized and parallelized (see [1.2.1 on page 5](#)) it cannot be fast as an application software, because JavaScript must be interpreted by the browser and then executed as machine code. [WebCL](#) provide an easy framework for building and running machine code in parallel directly from the browser.

- Come usiamo noi queste tecnologie
- task monitoring
- SIFT??

¹² A programming language dialect for the past C developed in 1999 (formal name ISO/IEC 9899:1999)

2 | THE MODEL

In this chapter, we define the *architectural model* for our system and the reference infrastructure supporting this model. The *architectural model* is the data model on which the single components of the system are built upon. It describes the components that interact each other during the task lifecycle and embodies also the requirements and the features of the system as expressed in the [introduction](#).

Concerning the data model we have subdivided it in 3 parts, this subdivision is made to better distinguish each of the 3 main steps used in every distribution system in order to create, distribute and process the data. ?? gives an overview of the *architectural model* that is composed by:

THE ARCHITECTURAL MODEL: describes the reference architecture .

THE DATA MODEL: describes all the actors and stakeholders present in our system.

THE EXECUTION MODEL: focuses on the model of the task and the users with their characteristics and proficiencies.

PLUGGABLE STRATEGIES: here we focus on the provide some example of usage.

2.1 ARCHITECTURAL MODEL

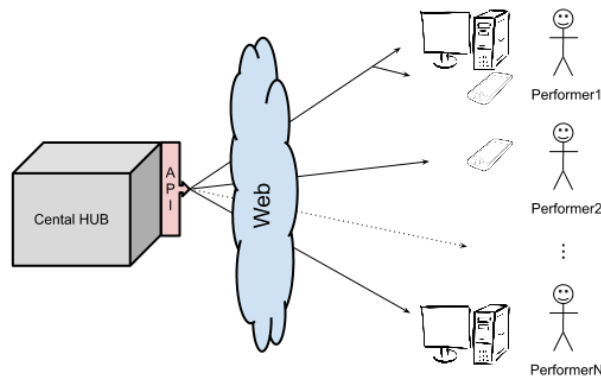


Figure 1.: Reference architecture.

The system use as a reference architecture the one depicted in [Figure 1](#). Here we have a centralized hub that *defines* and *distribute* the

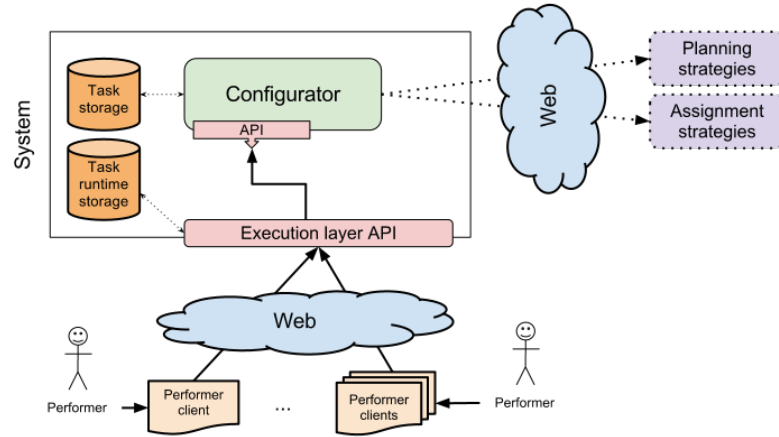


Figure 2.: Specialized architecture.

workload, a plethora of clients with their browsers and the users. The clients of this model are all coherent and transparent to the execution of the code, which is distributed to the end-user according to the platform they are using. As you can see the structure is almost the same as any other task distribution platform, the strengths of this system are in the characterization of the actors in the system.

The reference model in Figure 1 has been customized to meet our needs of flexibility and pluggability, so we introduced a *configurator* and a *execution layer* in the central hub. These are the components that allow our system to cover all the dimension presented in Table 1.

The **configurator** is in charge of defining and configuring a task in the system, allowing the *requester* to add hooks to external resource in order to manage the assignment cycle and the planning strategy.

The **execution layer** provides useful API for managing the μ Task and communicate with the *configurator*.

2.1.1 Configurator

This component is the kernel of the task creation and configuration. Provides the following functionalities:

- To allow a Requester to configure (at an abstract level) a new crowdsourced task by using the Configuration UI
- To allow a Task/Job Creator to monitor the execution of a crowdsourced task
- To allow a Performer to execute the assigned activity (Micro Task) by using a default, not configurable UI.
- To allow a CrowdSearcher Task/Job Client application to
 - Create, configure, and monitor a (set of) Task(s), Please notice that the orchestration of several tasks is managed externally from CrowdSearcher.

- To retrieve the set of Micro Task associated with a Task.
- To post the result of a Micro Task execution.
- To get notified about the completion of a Task / MicroTask

2.1.2 Execution layer

Execute

2.1.3 Task sotrage & task runtime storage

Store

2.1.4 Performer & Performer client

Performs

2.1.5 Planning strategies

Plan

2.1.6 Assignment strategies

Assign

2.2 DATA MODEL

data model

2.3 EXECUTION MODEL

Execution model

2.4 PLUGGABLE STRATEGIES ASSIGNMENT

Pluggable+Strategies

3 | THE USE-CASES

3.1 AUTOMATIC

Automatic Voluntary
Machine driven Scale-Invariant Feature Transform ([SIFT](#))

3.2 HUMAN

Dato un testo disambiguarlo usando YAGO (AIDA, <https://d5gate.ag5.mpi-sb.mpg.de/webaida/>), EntityPedia?, e altri *Modernizr*

3.3 HYBRID (AUTOMATIC+HUMAN)

Hybrid (Face recognition)

4 | IMPLEMENTATION AND EVALUATION

4.1 ARCHITECTURE

4.2 PERFORMANCE COMPARISON???



CONCLUSION AND FUTURE WORKS

ACRONYMS

| | |
|---------------|---|
| HTML5 | HyperText Markup Language version 5 HTML5 is a markup language for structuring and presenting content for the World Wide Web, and is a core technology of the Internet originally proposed by Opera Software. |
| WebCL | Web Computing Language The WebCL working group is working to define a JavaScript binding to the Khronos OpenCL standard for heterogeneous parallel computing. WebCL will enable web applications to harness GPU and multi-core CPU parallel processing from within a Web browser, enabling significant acceleration of applications such as image and video processing and advanced physics for Web Graphics Library (WebGL) games. |
| SIFT | Scale-Invariant Feature Transform SIFT is an algorithm in computer vision to detect and describe local features in images. |
| OpenCL | Open Computing Language OpenCL is a framework for writing programs that execute across heterogeneous platforms consisting of CPU, GPU, and other processors. OpenCL includes a language (based on C99) for writing <i>kernels</i> (functions that execute on OpenCL devices), plus APIs that are used to define and then control the platforms. OpenCL provides parallel computing using task-based and data-based parallelism. |
| WebGL | Web Graphics Library WebGL is a cross-platform, royalty-free API used to create 3D graphics in a Web browser. Based on OpenGL ES 2.0, WebGL uses the OpenGL shading language, GLSL, and offers the familiarity of the standard OpenGL API. Because it runs in the HTML5 Canvas element, WebGL has full integration with all DOM interfaces. |
| CORS | Cross-origin Resource Sharing Cross-origin resource sharing (CORS) is a web browser technology specification which defines ways for a web server to allow its resources to be accessed by a web page from a different domain. Such access would otherwise be forbidden by the same origin policy. CORS defines a way in which the browser and the server can interact to determine whether or not to allow the cross-origin request. It is a compromise that allows greater |

flexibility, but is more secure than simply allowing all such requests.

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| RIA | Rich Internet Application Rich Internet Applications (RIA) are web-base application taht have many of the characteristics of desktop application software. |
| HIT | Human Intelligent Task |
| TCP | Transmission Control Protocol |
| AJAX | Asynchronous JavaScript and XML |
| CSS3 | Cascading Style Sheets |
| BOINC | Berkeley Open Infrastructure for Network Computing |
| GWAP | Game With A Purpose |
| GPGPU | General-purpose computing on graphics processing units |
| SETI@home | Search for Extra-Terrestrial Intelligence <i>at</i> home SETI@home is an Internet-based public volunteer computing project employing the BOINC software platform, hosted by the Space Sciences Laboratory, at the University of California, Berkeley, in the United States. Its purpose is to analyze radio signals, searching for signs of extra terrestrial intelligence, and is one of many activities undertaken as part of SETI. |

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