On the Smart City and Space-Based Computing

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As predicted for decades by engineers and science fiction writers alike, computers and their associated joys and frustrations are entering the city. Not entirely unlike other mass migrations of human immigrants, as computers permeate our urban spaces they simultaneously break apart its traditions and blend into the background of the culture, adopting surrounding mores. To date when viewing the exodus from desktop to blacktop, society has thought not in spatial terms—as a movement from indoor *places* to exterior *environments*, but in terms of technological, object based additions. This merger of urban space and computational objects and networks serves as an impetus for the development of a framework that merges the ubitquitous computing mantras of technologists with existing spatial theories, as developed by professions of location [1]. We call this collision between the architecturally defined areas and digitally bound technologies *Space-Based Computing*.

A new space for computers: The City

Somewhat like weeds entering a garden, computational goo (the collective set of pervasive wireless networks, autonomous agents, sensor arrays, electronics, satellites, databases, etc) is springing up in the public realm. Suddenly city streets, airports, movie theatres, sidewalks, parks, agoras, and the like are seeing the introduction of a computational layer that promises

to make them intelligent, context-aware, and packed with sensors. Motivations for this entry of goo into the outdoor community mirror classical incentives for creating the city itself—cities bring better security, increased efficiency, an ability to conduct commerce, and the benefits of a specialized workforce.

As these technologies enter the realm of the city they bring with them new ways to strengthen the benefits of urban life and reinforce its internal essence. Author and urban theorist William Whyte noted that it was the job of the urban planner to "maximize the potential" of any given space. With Whyte's maxim and the new technological tools in hand, we challenge the professionals of location and engineers or other self-proclaimed technologists to work together to create a theoretical framework for Space-based Computation, and thus enable the maximization of the potential of the computational-enhanced city.

At such a juncture it is appropriate to remind us that all too often technological advances are rife with repercussions that may take years to be made apparent. As computer goo emerges in the urban environment we are faced with the largest interjection of technology into the city since the automobile and the highway were invented. It is from this perspective, the perspective of the automobile, that we are able to gain tremendous insight into the challenges that face this, and any major infrastructure infusion. In retrospect, it is easy to see how the automobile was both a blessing, tying together nearby communities and gaining access to resources on a regional scale, and a curse—blindly consuming natural resources without global consideration of consequences. With goo promising to become as common on our streets as the automobile is today, we, the designers and creators of tomorrow's city,

need a framework that allows us to consider the impact of these new technologies on society. Such a framework will allow us to engineer, analyze, and optimize the good of the technology before its irreversible entrenchment into the environment. What follows is not the framework for Space-based computing, but a start in the discussion of what Space-based Computing, or whatever grouping of words that embodies these ideas, might be.

The challenge of interface

We start by noting that interesting events occur when two things collide—regardless of whether the things colliding are humans (friends meeting each other on the street), computer-human interfaces (an algorithm controlling a stoplight, and thus traffic flow on the street), or computer-computer interfaces (a digital security agent contracting the federal government's Department of Homeland Security web site to see what the current "threat level" is [2]). It is this challenge, the challenge of interface, which Spaced-Based Computing attempts to uncover and help answer. We hope to provide guidance for future designers (who may wear the mark of any one of the new professions of location, which furthermore should include computer science, engineering, and politics) for deciding the optimal and appropriate interaction between these three interfaces:

- ?? Human to Human Interface
- ?? Human to Computer
- ?? Computer to Computer

By involving space-based designers in the study of computer systems it should become clear to both parties that there exists a link between city form and software development. Like the city itself, modern software is an amalgam of numerous independent and complex parts whose exact inter-relationships are more experientially constructed than scientifically composed. Our work attempts to build models of how future communities reorganize with the aid of these digital interfaces, and readily encourages professions to borrow tools from each other.

Current technological motivations

Before disembarking, we would like to highlight a few particular pieces of technology that motivate the study of Space-based Computing; it is precisely technologies like these that, as they take hold, suddenly force the rethinking of some of our basic assumptions about the roles for citizens, technology, and the process of design itself.

The first is the pervasive wireless networks that blanket much of the world—from cellular telephone to satellite GPS transmissions to 802.11 and radio broadcasts. With recent generations (and certainly future ones) of the cell network having data transmission capability a new invisible transportation layer has been added to our cities. With this pervasive network attached to the global Internet, devices can be both dumb and omniscient simultaneously. We note that being dumb is a highly attractive property in that dumb computers are usually cheap computers.

The second technological breakthrough is in the area of power storage and generation. All organisms need to get energy from someplace. Some organisms use osmosis, others hunt, and modern humans indirectly obtain energy through the utilization of specialization and farming. Current computer devices operate on electricity, so they need to be either connected to an electricity-producing device (via a power cord/transformer) or generate their own electricity from either solar or electromagnetic absorption techniques. An interesting byproduct of the first technological trend mentioned, the radio layer on top of the city, is that the transmission of radio waves is essentially pumping electricity into the air. For those receivers tuned into the transmission these electromagnetic fluctuations can be turned into a signal and "understood". However recently engineers have noticed that you can gain small amounts of power from the air and store it in a capacitor for later use by the third technological trend, the low-power, sometimes on, ultra-redundant computer. Other technologies are on the horizon that get at the power problem from another angle: the produce it in the form of environmentally friendly fuel cells.

Finally, truly mini computers, with names like "smart dust," "quantum computers," or "paintable computers" provide a window into the current attempts to grow miniature digital devices capable of many thousands of operations per second. Of particular interest is the notion that each individual computer does not have to "get it right," but simply communicate with others incase it does. Like the mutation of an organism over time, the important part is that the group is generally adding value to society and its space rather than creating problems. We can think of this class of computation as embracing emergent design and iteration versus monolithic programs that ask questions and give answers.

The goal: the post-integrated city

Space-Based Computing then is a study in finding methods and guidance to the challenge of integrating computers into the city, with the aim of creating a "post-integrated city" where computers and humans share their environments. We can imagine ourselves on a continuum from disparate computer/human realms to a fully integrated reality where computer space and human space are one. As we move further in time, towards this post-integrated city, the once-clear demarcation between the virtual and the real worlds are increasingly difficult to visualize, even when visiting real-world mainstays such as urban streets.

In order to reach such a state of integration between humans, environment, and computers, we consider shifting some of our current concepts about the social roles of the computer. In particular, we investigate:

- ?? Human Computer Environment Interaction (HCEI),
- ?? Goo as Servant,
- ?? Security, Sensors, and Government

Human Computer Environment Interaction (HCEI).

This is the slight alteration of the HCI paradigm, which studies how computers and humans interact with each other. In HCEI, instead of the humans and the computers directly interacting they do so by manipulating the environment they are within. We shift the scale of the interaction to that of the environmental level. For example, traffic sensors that change the stoplight when a car approaches is an example of a simple version of this trend.

HCEI acknowledges that we are building an invisible layer on top of our existing city, a layer whose goal it is to interact with the environment for the good of the city. This layer consists of interconnected sensors, computers, networks, and radio links that allow for *locational all-at-oncedness*. HCEI further promotes the merger of the "everywhere consequence" of the Internet with the "just here" properties of being physical.

HCEI is more of a technical area of concentration to figure out technically how to build the city. How do we mix the mortar/flatten the trees/irrigate the crops? One approach is to design an "agar", a contained space in which digital life can flourish, yet be controlled and contained? Current trends such as P2P data storage, global information retrieval (ask the Oracle, but get a parsable response), and tainted data security play a roll in the development of HCEI. Other projects, such as MIT LCS project Oxygen, or UIUC's Gaia [3] similarly remind us to consider the global impact of individualized design decisions.

Goo as Servant.

Tools are the servants of man. Science fiction authors have dreamt of a land in which computers (or robots, serfisms, or whatever they might be called) enable humans to lead better lives, delegating some of the menial tasks to the servants, so the humans can take the role of philosopher kings. Is our digitification essentially creating this servant layer? If so, can we be explicit about the role of computer technology and the expectations that each side has of each other? Who does a piece of computer code "report" to? Is there need for such a hierarchy, or is an emergent system better suited for this job? If we use an emergent system, how can it be properly "contained"? What happens when your servant and my servant want to share data about me (or you?). What kind of "bill of rights" do humans and

computers have? Do we have one servant, or is it simply an interaction with the environment and the many digital elements of the environment? What can be learned from biological systems regarding the homogenization of code/operating systems?

Security, Sensors, and Government.

There exists three main participants in the digital city: human citizens, government (including infrastructure and its human/digital agents), and digital organisms (including citizen, government, and digital offspring). The interplay between these participants directly influences quality of life for the city. In particular though, what is the role of the government?

The wall has a long been a foundational device to support and protect living establishments, yet today's city has little in the way of keeping out those armies that wish to do harm. The recent terrorism events around the world are evidence that it no longer takes an army of thousands to do significant harm. Furthermore, a wall (or even a city-wide bubble) is of little use when harm to citizens can come both from within (physically), or via electronic pulses from another corner of the globe (or even of the universe). How can we protect ourselves from widespread harm? How can we empower our government to protect us and still maintain our rights as individuals? Who owns data about our movements throughout the city? How can we ensure that new digital layers won't be used against us? What is the role of government in a new arena of codified rule, where computer programs could be certified to obey the law and be pre-destined to do "good " with any human-tainted data? What happens to government when our customs have been automated? Is this even a reality worthy of entertaining?

The global environment in the year 2003 is anything but stagnant. We have got as many ideological disputes as we have ever had and we are told that we have a larger potential that relatively small portions of our global population could wipe out large portions of geographic population. Terrorism is the word of choice to describe an increasingly broad series of activities that are the output of a tension of clashed ideologies. Within a networked world the ground sometimes feels like it has been taken from under our feet. Does geography matter when we are everywhere with the Internet? How can we balance the rights of individuals to live and reside with autonomy whilst keeping the city's history of protection? How can we create a modern city wall that builds community even if we lose geography? Are there other solutions besides pure governmental knowledge, *a la* 1984?

Modern citizens are governed by a set of general principles that tie together their society. In the United States, broad statements in the Constitution and Bill of Rights set forth the basis by which society functions. We assert that we need to revamp or create rules that acknowledge that we are living alongside digital organisms, which while extensions of ourselves, are autonomous and have a rigid interpretation that usually lacks the benefit of context for interpretive filtering. This area of research presumes that we continue to grow increasingly sophisticated digital organisms, and promotes the authoring of a guideline to judge their behavior against, to insure that digital life "plays nicely" with our world and not displace the human's place at the top of the hierarchy.

1 http://www.cs.colorado.edu/~palen/chi_workshop/papers/townshend.pdf

2 http://www.hewgill.com/threat/

3 http://devius.cs.uiuc.edu/ActiveSpaces/