

# Core Tangibles and Tangible Visualizations: prospects for tangible convergence and divergence

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## ABSTRACT

We describe efforts toward “core tangibles” and “tangible visualizations.” These combine both convergent and divergent approaches toward the advance of tangible interfaces as a practical, useful approach for computationally-mediated interaction. We also describe several key enabling electronic, programmatic, and web-based tools.

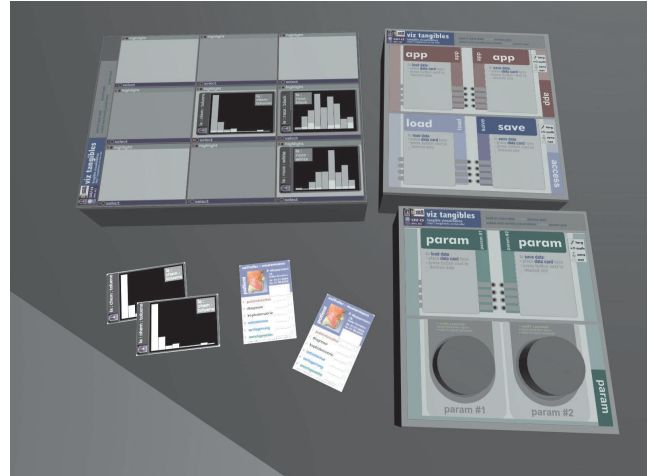
## INTRODUCTION

Both academics and the popular press have long celebrated prospects for technological “convergence.” In 2006, whether one views set-top boxes, cell phone/mp3/camera/PDAs, or beyond, convergence and functional integration are now mass-market realities. Further progressions toward “smaller, faster, cheaper, and more of them” seem inevitable [2].

In parallel, prospects for *divergence* and *dis-integration* (functional decomposition) in the forms and interfaces of computationally-mediated systems are also gaining traction. Buxton makes the comparison between multi-purpose Swiss Army knives and “simpler specialized devices, each of which may well be kept in a different location,” noting that the latter is often preferred in daily practice [2]. The site [7] presents more than 300 appliances, vehicles, wearables, and beyond which are based upon embedded Linux systems, but externalize their interfaces in forms which often cannot be recognized as computer consoles or other WIMP GUIs.

User interfaces like DataTiles [11] have begun to illustrate concrete approaches by which both functional decomposition, and grammatic composition of the resulting subelements, can be realized. Also, efforts such as [1, 3–5] consider prospects of divergent, decomposed interfaces for the critical usage context of colocated collaboration. We believe such examples illustrate the emergence of rich, diverse, complementary ecosystems of both convergent and divergent computationally-mediated devices and systems.

Our research centers on applications of tangible interfaces for visualization, simulation, presentation, and education, often toward collaborative use by scientist end-users. Both



**Figure 1. Core tangibles:** illustration of several interaction devices used in combination with RFID-tagged “data cards” to collaboratively interact with a visualization (Figure 2). The right devices are “pages” composing two “interaction pads” (now replaced with four 10x10cm “interaction tiles”).

within these contexts and more broadly, we see convergence and divergence as critical, interdependent themes for tangible interfaces and other physically-situated interaction techniques. In response, we are developing two complementary approaches: *core tangibles* and *tangible visualizations* – complemented by several key enabling technologies.

## Core Tangibles

Most tangible interfaces have existed as isolated islands. Inspired by Durrell Bishop [10], we see open-ended, ad-hoc, and exploratory combinations of diverse interoperating digital artifacts as among the most promising prospects of tangible interfaces. To date, this has rarely been possible.

Moreover, many common, critical operations within GUIs – e.g., opening and closing applications; loading, saving, and navigating data; and adjusting parameters – have generally remained inaccessible from tangible interfaces. Instead, users have been required to “leave” the TUI to interact with GUI consoles or command shells; to rely upon a supporting human operator; or to settle for highly limited applications.

In response, we are developing “core tangibles” [14]. Core tangibles support “core operations” which are common across a broad spectrum of applications, including data + ap-

plication selection and invocation; parameter manipulation; discrete and continuous navigation; and spatial placement. We currently embody core tangibles as modular, composable tiles, building on an approach introduced by DataTiles [11].

We anticipate core tangibles serving several major roles:

- enabling modular, composable, open-ended re-use of core operations across diverse applications;
- providing “in-band” access to core operations, rather than requiring dependencies on GUIs or human operators.
- supporting collaboration among multiple colocated and/or distributed participants, by decomposing the interface into multiple discrete, semi-independent display + control components, which are coordinated by shared graphical, audible, and haptic displays.

Core tangibles illustrate a kind of “convergence” in the area of tangible interface design. On the one hand, individual core tiles are specialized, both in their faceplate controls and underlying function. Simultaneously, they embody “convergent” functionality that is common across many applications, and potentially can be used in combination with many different kinds of interfaces (including GUIs, AR, VR, speech/gesture UIs, et al.).

### Tangible Visualization

While core tangibles address a kind of “tangible convergence,” we are even more strongly invested in “divergent” tangible interfaces that are more specialized and physically representational in form. Specifically, we are developing a class of highly specialized, divergent interactive systems that we call “tangible visualizations.”

Tangible visualizations can be seen as “physical descriptions of complex systems.” Our approach seeks to realize systems of specialized interaction devices which physically represent specific data, operations, and application domains. These are often intended for collaborative use (both colocated and distributed); and often in service of visualization, simulation, presentation, and education.

We continue by describing two usage scenarios for core tangibles and tangible visualizations. The first is an approach for collaborative visualization; the second is an interactive physical description of a major network infrastructure and its associated resources. We briefly discuss related work, and introduce several key electronic, programmatic, and graphical enabling technologies.

### SCENARIO 1: COLLABORATIVE VISUALIZATION

One of our main driving applications is support of interactive, collaborative visualization of scientific content. Computation had made a major impact on the pursuit of science. Data acquisition/digitization, simulation, and computational analysis are routine across many domains. In each case, visualization takes on a critical role for meaningfully engaging with large quantities of data.

Collaboration is also critical to many aspects of science. It may take place between peers with aligned or complementa-



**Figure 2. AccessGrid-linked meeting; core tangibles in use** (co-located and distributed users collaboratively manipulate a visualization application. Five sets of tangibles (three local, two remote) are used together with data cards to load and save data, manipulate parameters, etc. Most functionality is operational, but image is composited.)

ry expertise; between instructors and students; and in outreach with the general public, among other contexts.

We are working with a team of diverse scientists (physicists, chemists, biologists, ecologists, et al.) who are actively engaged in collaboration and dependent upon visualization. Their collaborations are both colocated and distributed (spanning multiple campuses and continents). They are heavy users of roughly a dozen “AccessGrid” video conferencing rooms spanning as many different sites. Each room has two or three wall-projections, 6-10 pan-tilt-zoom cameras, and network connections ranging from 100Mbps to 10Gbps (Figure 2a).

In meetings within AccessGrid rooms, “interaction” with visualizations is almost exclusively conducted using two software platforms: distributed PowerPoint and movie players. Generally, all interaction is controlled directly by the dedicated AccessGrid operators (who typically must simultaneously manage ~5 computers, 5-10 video links, and numerous applications). Thus, these visualizations not only fall short of collaborative control; often, they are not even under direct control of the presenters. While this is the most sophisticated and heavily-used video conferencing setup we have encountered, no one is satisfied with current visualization support.

We have received funding to develop a new approach for collaborative visualization, and to deploy our system and bring it into daily use in more than a dozen AccessGrid (AG) rooms. We have made three successful tests of our early hardware and software in meetings spanning three sites – Baton Rouge; Seattle/San Diego; and Brno (Czech Republic). These were linked by hi-def, low latency video conferencing (three channels video, one of shared 3D visualization) over dedicated 10Gbps network connections; all interaction with visualizations was controlled by our tangibles.

We anticipate interaction with core tangibles in this context to take roughly the following form. Each participating site will project one or (usually) more camera-fed remote video links; one or more shared visualizations; and a viz/interaction status display (Figure 2a,b). The AG operator will continue (at least initially) to maintain control of the video links, while control of the visualizations will shift to the conference participants (we expect to deploy 2-4 sets of tangibles within each AG room).

All conference participants will have the ability to load shared visualizations; alter both visual (rotate/zoom/...) and functional (time step/slice #/...) parameters; capture screen shots; and perform other operations via the core tangibles. In a conference with three sites, each with three sets of tangibles, this means that up to ~nine different participants can potentially take interactive control of the shared visualizations. (We expect the actual number of involved participants will be more, as multiple can share a single set of tangibles.)

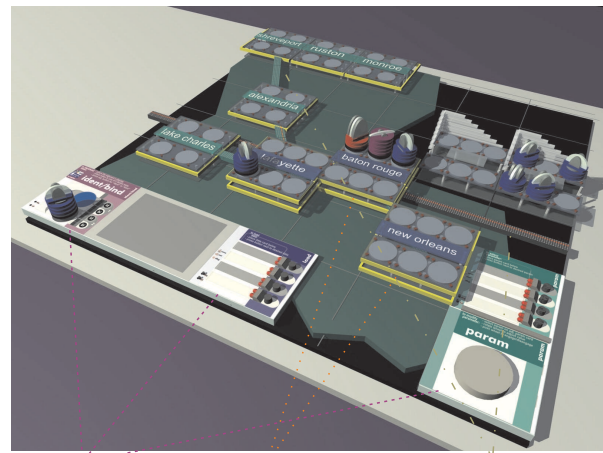
We anticipated and have observed that maintaining awareness and harmonizing collaborative interactions is both a challenge and potential strength of our approach. We are addressing collaborative control in several ways, including automatic software “clutching” to mediate handoff; visual feedback, both on shared projection displays and on the interaction devices themselves; audible feedback; and force feedback.

## SCENARIO 2: LONIWORKS

The above scenario describes the use of “convergent,” widely-applicable interaction devices. In contrast, our “LoniWorks” scenario centers upon “tangible visualizations:” special-purpose, “divergent” interaction devices which take the form of physical models specific to particular problem domains. Simultaneously, LoniWorks itself depends upon core tangibles, illustrating interdependence between convergent and divergent interaction approaches.

LoniWorks’ target domain is the Louisiana Optical Network Initiative (LONI). LONI is a \$40M, 10-year project to deploy a 40Gbps network backbone and compute infrastructure across Louisiana, linked with the national NLR infrastructure. LONI has many research, commercial, and public service implications. E.g., terabyte-sized Hurricane Katrina recovery datasets which took roughly a week to transfer could be transmitted with LONI in roughly 4 minutes.

However, LONI is a complex infrastructure. Its capabilities and behavior are unlike existing infrastructure; e.g., in contrast with mainstream Internet carriers, it is based on band-



**core tangibles:** basic operations such as load, identify, bind, modify params  
**embedded linux pda:** allows limited graphical interaction with several core operations (e.g. ID and bind tokens to machines, jobs, etc.)  
**network nodes:** nodes for each LONI terminus. each node includes array of pads for placing  
**resource tokens** (representing super-computers, vidconf, ...)  
**network paths:** LED matrix (4 wide, one LED per network lambda); red = LONI, blue = NLR

**Figure 3. LoniWorks:** tangible visualization of network. (high-resolution; PDF of image can be viewed full-screen)

width reservations and dedicated channels. This makes it potentially difficult to understand and control by its end users: research, commercial, and public service users who are not themselves network specialists.

We have begun developing a tangible visualization of LONI, providing a physical, manipulable model of the infrastructure, its network traffic, compute jobs, videoconferencing, and other activities (Figure 3). We believe this will be valuable in helping a diverse audience to collaboratively understand, use, plan, and manage this critical resource.

For example, consider Figure 3. Distinctively shaped tokens represent major LONI-linked resources. Specifically, major compute clusters are represented. The number of layers represent the number of CPUs  $\log_4$  (16 processors = two layers, 1024 processors = five layers, etc.), allowing diverse resources to be physically compared. Similarly, the height and width of arced token tops represents node and system RAM (which can be more important than CPUs for computations such as bioinformatics). Colors code for different vendors. Resource tokens are embedded with RFID tags, allowing their placement on different network nodes to be monitored.

While the forms of these tokens are still undergoing refinement, and important supporting textual annotations are not shown, we believe they will allow both technologists and the broader public to qualitatively distinguish, compare, and interact with diverse compute resources. (We are also developing tokens representing video conferencing facilities and other major LONI resources.)



Many tasks (e.g., hurricane and coastal erosion simulations) involve coordinating multiple computation resources and multiple teams spanning the state. Manipulating these resource tokens on the LONIworks interface allows users to marshal and configure resources; monitor network traffic on the LED-illuminated network paths; query and browse logs of past LONI utilization and scheduled reservations; and perform other key tasks. While supporting only a fraction of the operations accessible to a network professional at a traditional computer console, the interface should be far more accessible for education and end-user interactions.

## RELATED WORK

The background for core tangibles is described in [14].

Broadly viewed, the tangible visualization approach extends into prehistory. From before the era of digital computing, we find precedent in board and card games (with a 5,000 year history); the memory boards and Tjuringa of Africa and Australia; the early mechanical controls for the Panama Canal; and mimic boards and map boards (once used widely in industrial and transportation control centers, later in tiled forms).

The term “tangible graphics” has long been used in the blind community, as a descriptor for diagrams in physical relief which support tactile inspection. Within HCI, the term “tangible visualization” was perhaps first used in 2001, in conjunction with three related papers. Strata/ICC [12] and preceding work [13] lead directly into the present work. Patten et al. [9] used the term “tangible visualization” to describe the use of a general-purpose tangible interface to interactively manipulate graphical visualizations. Also, Marti et al.’s [8] “WeatherTank” created a “tangible visualization” as a kind of vivarium which potentially could be mapped to illustrate the dynamics of diverse information feeds.

## ENABLING TECHNOLOGIES

Our work is closely linked with the development of several key enabling technologies. While mostly beyond the scope of this short paper, we introduce these briefly below.

### Electronics

The core keyboard/pointer/display interaction model underlying the GUI/WIMP paradigm has remained relatively stable for roughly 30 years. In contrast, tangible interfaces typically force developers into an intimate relationship with electronics, mechanics, and firmware. Given the central role of physical form in TUIs, we believe the need for their designers to possess rudimentary electronic and mechanical fluency is likely to remain. However, relatively few HCI research labs have the human resources to deal with major electronics and mechanics development.

Moreover, the need to build up each TUI from the lowest level of abstraction constrains the complexity of what can reasonably be designed. In particular, we believe the “tangible visualization” approach ranges from impractical to implausible, if each system must be developed from the microcontroller and resistor level.

In response, we are developing “function blades,” which expose sensing, display, communications, and computation capabilities in a consistent, modular, extensible, easily employed fashion. These blades are each 10x2x1cm in size, corresponding to the 10cm modal length defined by human’s palmar hand grasp posture. Each blade has two 14-pin (7x2) DIP connectors. One connector is identical across all blades, and provides power and communications (both USB and I<sup>2</sup>C). The second connector’s function is entirely specific to the individual blade.

We use these blades extensively in both the tiled forms of core tangibles (which each accommodate 5-10 underlying function blades), and within our tangible visualizations. Non-blade electronics (e.g., Phidgets and Particles) can also be embedded within tiles using their standard USB and I<sup>2</sup>C buses. We also use tiles themselves as a kind of functional aggregation and scope (from a software and functional perspective) in our design of tangible visualizations (Figure 3). In order to support the evolution of tangible interfaces, we are working to release a suite of blades, core tangibles tiles, and associated software as open source hardware, firmware, and software.

### Software APIs

While we believe blades and bladed tiles could become an important technology tool for the development of tangible interfaces, diversity is a virtue, and tangibles using widely varying hardware/software toolkits should be expected. As we feel interoperability should remain a major TUI goal, resolving some form of hardware, software, and toolkit-independent device description seems highly important.

Toward this, we have begun working on several forms of XML-based device descriptions. One of these (in collaboration with Dr. Albrecht Schmidt) is at the hardware protocol level. This will allow diverse software to interact with underlying functions implemented by specific blades, Phidgets, Smart-Its, Particles, etc.

A second level of XML description relates to the composite functional roles of individual interaction devices. Here, we intend to expose an API which is largely independent of the underlying technical implementation. Thus, ideally an interaction device could be reimplemented with blades, Phidgets, etc., while leaving its external functional API unmodified. We are interested in finding ways to combine these efforts with others such as [6]. We are also exploring different kinds of registries and matching software for pairing interacting interaction devices together, including (e.g.) Prolog interactions with Grid-enabled SQL databases.

Finally, while we hope end-users will wish to interact with our tangible interfaces, we believe graphical interfaces and other interaction techniques will sometimes remain preferable. We also wish to map the same set of tangibles across various kinds of software implementations (e.g., visualizations using Amira, VTK, OpenDX, AVS, TechPlot, etc.). To support both of these ends, we have begun developing a “core operations API” (COA) and “InterViz API” (IVA) to descri-

be some of the high-level software functionalities we wish to control with tangibles and other interfaces.

### Web-based interaction

We expect tangible interfaces will in time fill certain useful functional roles, but many forms of HCI will continue to be carried forth using graphical interfaces. Correspondingly, we feel it is important to support “interaction life cycles” that can gracefully interlink tangible and graphical interaction.

We have begun to develop graphical, web-based “invitations to interaction” and “interaction take-aways” which are closely coupled with our tangible interfaces. As one example, we have created software which creates “viz reports.” These are web-based compilations of annotated images which are automatically generated as the product of computer simulations of various physical processes.

In addition to providing a visual overview, these viz reports serve as a launch-point and terminus for interaction. We are developing web-based means by which users can quickly transfer selected images (corresponding to “checkpoints” of manipulable, fully interactive visualizations) into “data cards” for manipulations with our core tangibles. Similarly, we are developing software for our core tangibles which allows them to (e.g.) “screen shot” visualizations together with associated parameters; and automatically synthesize viz reports composed of this content.

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