Tangible Interaction With Large Data Sets Using Active Tokens

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Abstract
We present our approach towards data physicalization – tangible interaction with active tokens for collaborative exploration of large data sets. Active tokens are programmable physical objects with integrated display, sensing, and actuation. We describe our approach, discuss its cognitive foundation, and present case studies, which we designed, implemented, and evaluated in order to investigate the usability and usefulness of this approach.

Author Keywords
Tangible interaction; physical tokens; cross-device interactions.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces---input devices and strategies, interaction styles

Introduction
Multi-touch and tangible interfaces provide unique opportunities for enhancing learning and discovery with large data sets. Such interfaces support distributed cognition by affording spatial interactions with information artifacts such as spreading, piling, and organizing, which are well suited for sensemaking [9]. Multi-touch and tangible interfaces also provide form factors that foster collaboration through visibility of actions and egalitarian input [5,6]. However, existing multi-touch and tangible interaction techniques have

limitations when exploring large data sets including small representations of data and controls, gesture discoverability, and identifying legible physical and visual representations of aggregated and dynamic data.

Considering these limitations, our research agenda seeks to define novel interaction techniques for multi-touch and tangible interfaces, which enhance the construction of complex queries for large data sets. We focus on investigating whether tangible interaction techniques can enhance learning and discovery in areas where a vast amount of abstract information (no inherent physical representation) is accessed and manipulated. Examples include molecular genomics, and synthetic and systems biology.

Tangible Interaction with Active Tokens

We propose that tangible interfaces with clear and immediate feedback as well as with strong constraints provide an alternative approach to traditional multi-touch WIMP element for exploring large data sets, enabling users to collaboratively engage in sensemaking and problem solving.

Such systems can utilize both soft (graphical) and hard (physical) tokens and constraints to guide users in querying and interpreting large data sets. Technological advances and mass-market offerings such as Sifteo Cubes, smart watches, and small robots (e.g. Sphero, Dot) open possibilities for the use of active tokens.

Active tokens are programmable physical objects with integrated display, sensing, and actuation technologies [12]. Thus, they can be reconfigured over time, allowing for the representation of dynamic and aggregated data as well as enabling users to dynamically modify tokens' associations with datasets or controls. The use of active tokens expands the design space of token and constraints interaction [10, 11], which leverages physical expression of digital syntax. Embedding active tokens within customized 3D printed casing could provide physical constraints and affordances, in turn helping users to make sense of the data and guiding possible interactions.

Combining interactive multi-touch surfaces with active tokens could facilitate the presentation and manipulation of large data sets while preserving the benefits of tangible interaction such as support for two-handed interaction, co-located collaboration, and strong affordances for spatial interaction. We focus on a sub-class of active tokens that can be manipulated using gestures independently from global constraints. Such active tokens enable the expansion of tangible interaction with multi-touch surfaces beyond interaction on-surface into less explored areas such as tangible interaction on-bezel and in-air, hovering above or in front of a surface.

Cognitive Foundations

Our approach of tangible interaction using active tokens is informed by evolving notions of cognition, which shed light on how people's physical actions and interactions with their environment support scientific reasoning [7].

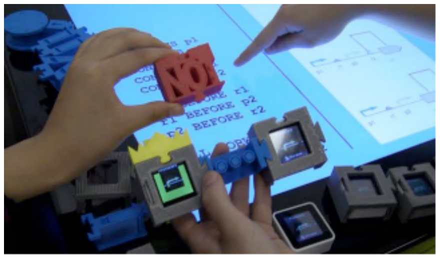

Figure 1, Eugenie++ combines active and passive tangible tokens for constructing complex queries. Results are presented on and interactive tabletop.

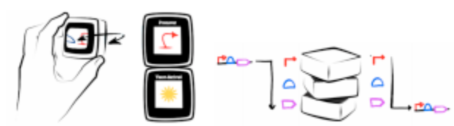

Figure 2, Eugenie++ provides gestural and tangible interaction techniques for browsing large data sets: (left) tilting to search, neighboring for traversing an hierarchical database; (right) stacking to collapse and expand biological constructs.

From early childhood, our interaction with physical objects appears to be closely connected with our learning and thinking. For example, researchers have shown that touching physical objects can help children learn how to count [1]. In thinking about complex problems, scientists employ external artifacts (e.g., models, diagrams, instruments) to support their reasoning [8]. A famous example is the double helix model of DNA built by Watson and Crick, which enabled them to quickly form and test out hypotheses by manipulating the model's physical structure. Physical models can thus provide an entry point for the cognitive apparatus in the form of both conceptual and material manipulation [2].

Computational systems can also embody knowledge. Typically, visualizations are used to make computational models accessible to human cognitive capabilities. However, the interaction with most visualizations is not closely connected to the underlying model of the studied phenomenon or system. That is, the interactions users have with most interactive visualizations (e.g., using button clicks, menu selections, etc.) are very unlike Watson and Crick's manipulation of the physical DNA model. In the latter case, the actions made with the physical model were tightly coupled with the scientists' emerging conceptual model, which helped to leverage the connection in the brain between motor, perceptual, cognitive processes in the development of insights [3]. We believe that systems that employ active tokens have the potential to leverage gestural interaction in order to create a similar connection between the computational model/data and the user's conceptual model. Following, we describe two case studies – systems that we developed in order to study tangible interaction with active tokens for collaborative data exploration.

Case Studies

To date, the co-authors have studied users' expectation from tangible interaction with active tokens [12] and developed several systems that explore the use of tangible interfaces with active tokens. Our work draws and expands on Tangible Query Interfaces (TQI) [11], which introduced tangible interaction techniques for querying large databases. TQI utilized systems of tokens embodying query parameters. These were manipulated and interpreted using physical constraints. Here we describe two tangible systems that utilize active tokens to explore large biological data sets.

Eugenie++ [4] (see Figures 1 and 2) is a tangible user interface for helping synthetic biologists through the collaborative and data-intense process of bio design. It consists of a horizontal tabletop application and a set of active and passive tangible tokens. Active tokens, implemented using Sifteo Cubes, represent collections of generic or concrete biological building blocks. The active tokens can be manipulated through gestures (shake, flip), touch (swipe, click) and spatial interactions (neighbor, stack) in order to navigate the large data set (see Figure 2). We encased each block in a 3D printed cover that resembles a jigsaw puzzle piece (see Figure 1) to facilitate the connection of query operators. Query operators are statically bound to passive tokens, and are represented using various symbols. We believe that utilizing physical syntax to enforce query syntax combined with tangible and gesture-based interaction techniques for browsing large database enables users to explore a large design space effectively and collaboratively.

Pathways Builder (see Figure 3) is a tangible interface for constructing and manipulating biochemical pathways. It consists of a multi-touch tabletop application that provides a visualization of the overall reaction network, as well as a set of active tokens implemented using Sifteo Cubes. The tabletop application is based on our previous work on Kinesthetic Pathways [13], however Pathways Builder extends the interactions beyond the tabletop through the use of active tokens. The active tokens act as

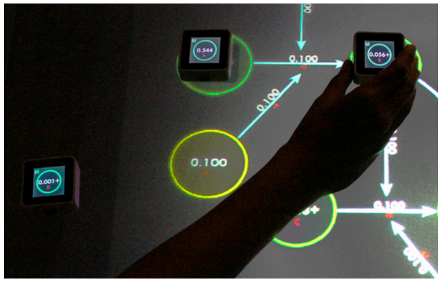

Figure 3, Pathway Builder combines active tangible tokens with graphical representations on an interactive tabletop for constructing and manipulating biochemical pathways.

objects in the system (e.g., molecules, reactions) as well as tools that act on these objects (e.g., dials). They can be manipulated using gestures (e.g., tilt, shake), touch (e.g., click), and spatial arrangement on and off the tabletop. We believe the combination of active tangible tokens and interactive graphical representations with flexible bindings between them can provide a powerful technique for manipulating dynamic systems such as biochemical pathways.

Taken together these two case studies demonstrate new interaction techniques with tangible representations of large data sets and control as well as highlight challenges and opportunities for applying tangible interaction with active tokens to the physical exploration of large data sets.

Conclusion and Future Work

We presented our approach towards data physicalization: tangible interaction with large data sets using active tokens. Active tokens extend the design space of token and constraints tangible interfaces and offer opportunities for rich tangible and gestural interactions with large data sets. Technological advancements including smart watches, small robots, and shape-changing materials, offer increasing opportunities to further explore novel tangible interaction techniques for data-intensive applications. We look forward to exchanging ideas with researchers and practitioners from various disciplines and to contributing to setting a research agenda and forming a community, which explore the physicalization of data.

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