Chapter 7 – Application planning

One of the mantras of software development is the need to always keep the application's user in mind; it is she that all our efforts are for. We need to understand what it is that the user is trying to accomplish, what her experience or skill level is, and how the task to be solved fits into a larger workflow and purpose. As such, application planning is very much like systems analysis, except that here the user is middle and centre of it all. One of the differences with GIS applications is the steep learning curve due to the complexity of the software. This chapter's first section discusses some of the ways researchers tried to address this issue. Following Lanter (, p. 1), "some of the most successful user interfaces are complete illusions outwardly bearing no resemblance to the data processing happening inside the machine". Users have mental models about the tasks they accomplish with a system, and the way the system lets them accomplish those tasks. These models are defined by the user's prior experience, existing knowledge, and preconceptions about tasks (Rauh *et al.*, 2005). For both a task and the way to accomplish the task to make sense, they must correspond to existing knowledge the user already has. Section 7.2 will dwell on this transition between the developer's view and the user's view of a GIS application. Formal specifications of both views are seen as a way to create a consistent user interface. For many years, researchers have been gathering user requirements, but as section 3 alludes to, this is becoming an increasingly futile business in the context of user generated compositions of web services. Clues may be drawn from another domain, that of workflow management in the business community as well as in scientific process composition. Sections 4 and 5 discuss different approaches in these two domains. It now turns out that all the work on GIScience ontologies has some very practical value in GIS application development based on the semantic web. Recent efforts in this realm are presented in section 6, while the remainder of this chapter provides pointers what technical and scientific developments to watch.

7.1. GIS interface complexity

Keeping in mind that GIS combines the functionality of database management systems and computer aided design software, it is one of the most complex widely used end user applications around. Not only does it typically consist of over a thousand functions but it requires the user to combine different metaphors and concepts borrowed from separate disciplines (Driver and Liles 1983; Mark and Gould 1991; Traynor and Williams 1995). In consequence, it usually takes a combination of multiple courses and years of experience to become a proficient user. A lot of this has to do with the multi-pronged origins of GIS itself: surveyors, landscape architects, and census statisticians, to name three prominent origins, have little in common but contributed approximately equally to the conceptualization what we now know as GIS. The National Center for Geographic Information and Analysis (NCGIA) conducted a series of workshops in the early 1990s that brought together experts from a variety of disciplines to tackle the complexity of GIS user interfaces (Frank 1993, Nyerges 1993; Turk 1993, Volta and Egenhofer 1993), resulting in a NATO workshop and Nyerges *et al*.'s 1995 *Cognitive Aspects of Human-Computer Interaction for Geographical Information Systems*. On the other side of the Atlantic, Medyckyj-Scott and Hearnshaw compiled in 1993 the first-ever compendium of GIS user interface research, while Davies (1998) did an excellent job analyzing the complexity of GIS tasks and user interfaces.

Case study 7.1 Development of a land use-based transportation model

Albrecht et al. (2008) describe a rather complex but fairly traditional GIS workflow (Figure 7.1 depicts the program's logic; the database schema is too deep to be represented in a single figure). Goal of this spatial decision support system (SDSS) is to model existing flow in a multi-modal network and to find optimal locations for transit hub based on existing parcel-level land use. The procedures of the SDSS combine many hundred GIS operations for a single model iteration.

The very model *structure* is dynamically changing as the model is run. For instance, the choice of a commuter's mode or route is influenced by how many other commuters crowd one's first or second option. Many commuter train riders, for example, are familiar with the added number of passengers when flooding closes roads during rain or snow storms. The same happens on a smaller but cumulatively as effective scale every day in metropolitan areas around the world. From an abstract perspective, the phenomenon is well studied and has become a popular example in complexity theory. From a user interface development perspective, it is almost impossible to create an easy to use and intuitive interface that hides this complexity from the user. Of course, sometimes it is quite useful, especially for the scientifically inclined user, to see this complexity.

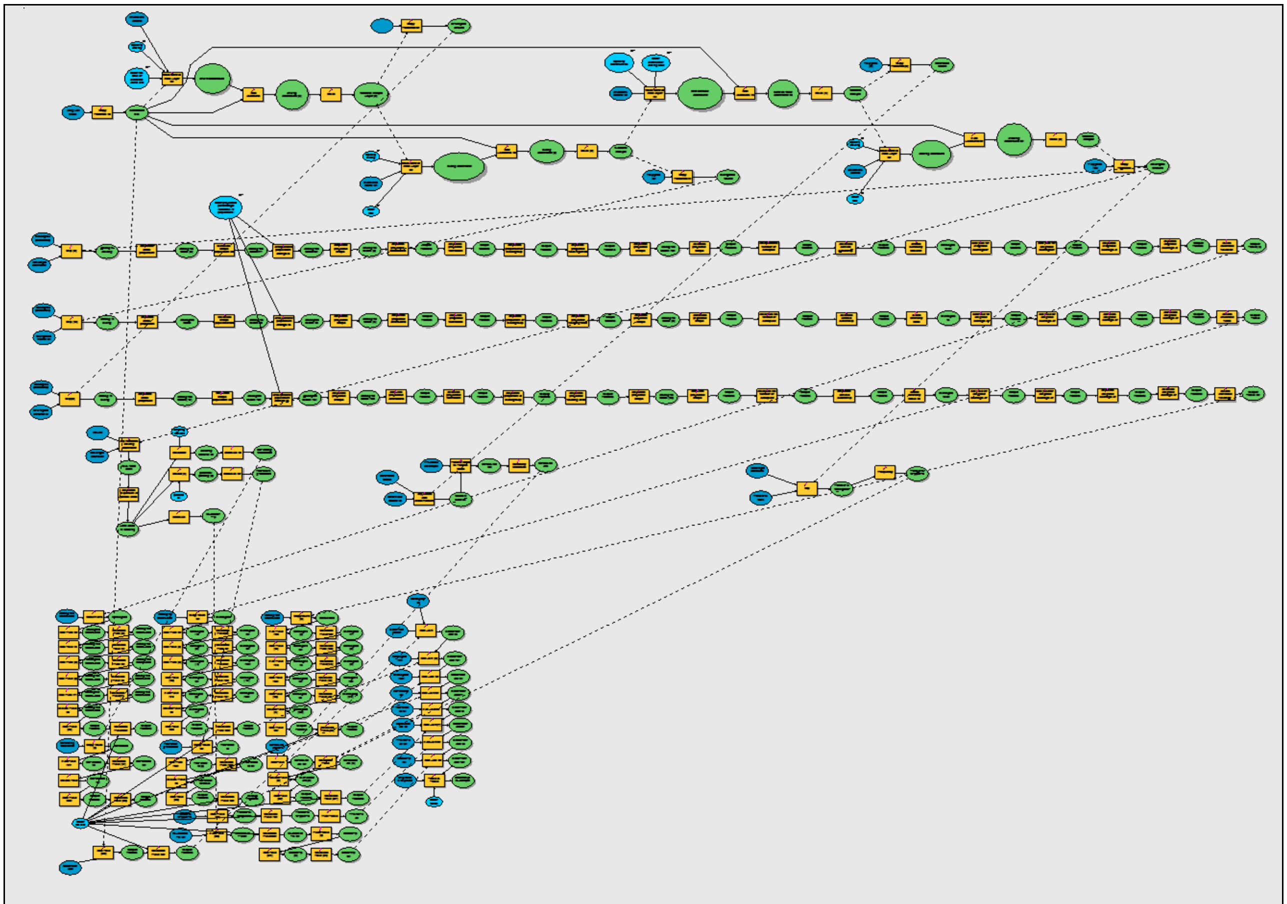

Figure 7.1. Top-level view of a land use-based transportation hub siting model.

Virtually unknown today, in his early career, Andrew Frank and Frank Egenhofer created at the University of Maine a cohort of graduate students that explored ways to tie the various perspectives together. Volta (1993) separated the formalization of the problem domain (identifying the objects a user manipulates, and their pertinent operations) from its visualization (describing human-computer interaction techniques such as windows and dialog boxes). Bruns (1994) tried to bridge the cognitive dissonance between table top and map space by creating so-called direct manipulation interfaces, where the user combines iconic representations of GIS objects aiming at a visual map algebra – a notion we will revisit in the section on GIS workflows and process models. Jackson (1990) recognized a series of mappings between three domains: the source domain, the target domain, and the user interface domain, or visualization. In his thesis 'Visualization of metaphors for interaction with GIS' he developed formal specification methods to describe the domains involved and identify similarities and dissimilarities between them. Gollege's (1995) approach to the same dissonance problem was to identify spatial primitives as building blocks of higher-level GIS operations and subsequently tasks. We will revisit this idea in a later section of this chapter. Albert and Golledge's (1999) thorough investigation of the cognitive aspects of map overlay and Riedemann's (2005) parallel work on topological operators seem to have brought a closure to the topic.

7.2. Formalized analysis of GIS user interfaces

With the advent of GIS as a potentially interesting research object in computer science, more formalized approaches to the study of GIS user interfaces began to appear. Kösters *et al.*, (1996a,b) took well-established methods from classic object-oriented systems analysis (OOA) and applied in parallel to (what developers believed are) the domain of GIS tasks and to the analysis of the user interface itself. Use of the same tool was supposed to guarantee that the 'mapping' referred to above could take place. If was a formidable effort that eventually failed because of the complexity of desktop GIS (they used a traffic simulation system) and subsequently the size of the formal analysis model. Li and Coleman (2005) use a similar instrument (now based on the unified modeling language) to describe workflows, not on the level of individual GIS operations but at that of user tasks. Their goal is quality control and the formalized approach certainly goes a long way assuring that.

Oliveira and Medeiros (1999, 2000) use considerable effort to formalize the static components of the user interface as well as a procedural view of how these are utilized. While their study objects are GIS and spatial decision support systems, this line of research of a group of information scientist who we will encounter in other parts of this chapter is decidedly not about user tasks or functional GIS components. The result is a dissection into software components (as in COM or CORBA modules) that are great from a software engineering perspective but are entirely void of any user experience considerations.

7.3. User experience considerations

Given the steep learning curve of GIS software, the user interface needs to be adaptable, i.e., work for the novice user as well as for the expert one. According to Mark (1992, p. 551), "a main objective of GIS is to allow the user of the system to interact vicariously with actual or possible phenomena of the world. If this is so, then the system which mediates between the user and the world should be as unobtrusive as possible". He goes on to distinguish between kinds of users (geographic knowledge), their computing skills, frequency of software use, cultural and personal background, and only then the purpose of the user's application. Davies and Medyckyj-Scott (1996) studied the first half of this list and concluded what seems obvious but had not been proven before: experience matters. Here, experience is the sum of educational level, familiarity with the software, and most significantly the match (or lack of) between the developer's and the user's conceptual model of the task at hand.

A user's experience is obviously strongly influenced by the culture she grows up in and the language they speak. Mike Gould (1989) built his early career on exploring the different spatial metaphors in English vs. Spanish and the effect that his on GIS usage. David Mark (1992) extended this to look at a range of other languages such as French, German, or Croatian. Following the work of Lakoff (1980) and Norman (1990), spatial metaphors and image schemata became a fertile research topic (Gould and McGranaghan 1990; Kuhn and Frank 1991; Mark 1992; Nyerges 1992).

Of particular interest is Nyerges' contribution, as he tries to identify cognitive primitives that can be used as building blocks representing elementary spatial relationships such as container, part-whole, linear order, link, center-periphery, etc. we will revisit this theme in section 7.5. Bunch and Lloyd (1996) give credence to the fact that managing the cognitive load experienced by learners is the key to representing geographic information.

Promising as this work looked back then, it has since only been advanced in linguistics and cognitive science but had no lasting effect on the design of GIS applications. As to cultural differences mentioned by Mark above, the notion that culture matters was picked up by social critics of GIS (Pickles 1995; Rundstrom 1995), but in the long run, market forces have proven to be stronger: GIS applications still look very much the same, no matter whether they are used in a London finance office, a school on a Navaho reservation, or a Nepalese erosion prevention program.

7.3.1. User requirement gathering in the age of Web2.0

Research on the material presented in the previous two sections has not been very active since the mid-1990s. There has, however, been a resurgence of interests on the remaining topics, mostly because of the transition of GIS applications from traditional desktop environment to distributed web services. Traditional application development methodologies such as Joint Product Design, Joint Application Design, Rapid Application Development, and more recently agile methods, assume that we can foresee the type of geographical questions to be asked and the characteristics of the application's user. More important, textbooks (Downton 1991; Whitten and Bentley 2005) advise us that we work with the user in reviewing the requirement list. However, in a Web2.0 environment, these parameters are not available anymore (Kazman and Chen 2009). Baranauskas *et al*. (2005) tried to address this problem by moving onto the web and conducting a public participation process to solicit input from potential users of a web-based GIS. Subsequently, and non-withstanding Brewer's (2002) call-to-arms, the only user requirements gathering for spatial applications that this author could find since are about mobile devices (Queiroz and Ferreira) 2009.

7.4. Task analysis as the basis for workflow management

With the user as a criterion out of the picture, we need to refocus on the set of functionalities available in GIS and related software. In the 1980s and 90s, Goodchild (1988), Lanter (1994), Jung and Albrecht (1997), and probably many more compiled lists of GIS functionality. In the age of Google's spatial products, the incorporation of spatial data structures and functions in the statistics package 'R', and numerous open source tools with varying degree of analytical functionality, the notion of what constitutes a GIS is a bit more fuzzy. The challenge is to match functionalities with generic user tasks, and most important to find means of communication that allow for that match to happen not just in a review article but in reality. Albrecht (1998) did this for the old world (i.e., traditional desktop GIS), and Klien *et al*. (2006) updated this line of work for web-based applications in disaster management. The following is a review of task analysis for geospatial applications.

Still on the desktop side, Oliveira *et al*., (1997) developed a processing environment, which is both more generic that Albrecht's (1998) VGIS and because of that less directly applicable to a GIS implementation. As such, it serves more as an application programming interface (API) for rapid prototyping of workflows in a multitude of application areas that requires a lot of fine-tuning to result in a user friendly application. On the upside is the possibility of linking applications from very different domains, on the downside, there is virtually no use of standards that we expect nowadays from interoperable software. Originating from the same research unit, Weske *et al*. (1998) describe possibly the same system, now called WASA, which becomes the foundation for two diverging developments. On one hand, they describe something akin to the scientific workflow environments that will be discussed in section 7.5. On the other, WASA is a precursor to a distributed, web-based toolset that is now at the heart of application developments world-wide covered in section 7.6.

Workflow management has become a major focus of business-related IT research. There are obvious gains in the rationalization of workflows, which have yet to make it into mainstream GIS. One aspect that links with past research in GIScience is the issue of quality management. Li and Coleman (2005), for instance, conduct their task analysis with the goal of focusing on quality control aspects of work flow management.

Geographers have maintained for generations that (spatial) context matters. Next to location and scale, context is at the core of geographic thought and theory (Spedding 1997, Massey

1999, Gertler 2003) and so it is a little surprising that this theme is now a hot topic in computer science rather than in the geographic roots of GIScience. Cai (2007) was the first to formally acknowledge the role of context in the specification of GIS tasks. This article ties together several strands of research described in different sections of this chapter. For one, he picks up Volta's formalization of mappings from the developer's view to the user's view, albeit now with modern ontology tools. Cai also employs user input to fill gaps in the specification of context that are to be expected in a distributed Web 2.0 environment. As such, he manages to keep his ontologies amazingly vague, with the system adding constraints on the fly as the user assembles the application. Liu *et al*. (2007) is a first report by a new research group at the National Center for Supercomputing Applications (NCSA) that picks up the context theme and a range of tools and software environments that help to build task ontologies (in particular for seismic disaster management) and end user ready decision support systems.

Case study 7.2 NASA's Earth Science Gateway

Bambacus et al. (2007) introduce ESG, a geospatial web portal designed to support prototyping applications and to reuse data by sharing Earth observations, Earth system modeling, and decision support tools. ESG's interoperability provides easy integration of systems and components through open interfaces for rapid prototyping. In their article, Bambacus et al. (2007) report on a rapid prototyping session during a GEOSS demo in May 2006. As do other countries and agencies, NASA and NOAA collaborate on modeling and predicting Earth science phenomena, such as global atmosphere circulation and wind speed. After the simulation results are produced, they are put into WCS and WMS and the services are registered into different catalogs, such as the Earth Science Gateway. In their workshop session, the participants used the ESG to rapidly prototype an application to identify locations for building wind farms to produce electricity in Hainan province, China.

The workflow consists of three main components:

1) Search ESG using "wind" to find services of interest from tens of wind-related services, such as G5FCST Wind Shear.

2) Add the G5FCST Wind Shear service that was found to the viewer to get the desired application.

3) The application shows some wind situations but no detailed wind speed information. Other services, such as the Mean Wind Speed service with rough and fine resolution are then added. This application can then be saved, and whenever a user brings up the application, updated observations and simulations will be integrated.

Through this process, an application can be prototyped quickly with the support of the ESG. In the process, users do not have to know who provided the observations or simulations, or who provided the external web Mapping Service (WMS). Professional users only focus on the application logic by searching available services and selecting needed services. Public users only need to bring up the application through an Internet hyperlink prepared by a professional. In this example, the legacy system of collected observation data and simulations of wind speed are leveraged in the find and bind process.

The ESG has the capability to bring up 3-D and 4-D visualizations and is targeted to serve the communities in sharing global earth observation data and simulations. Therefore, the ESG better serves the purpose of rapidly prototyping national applications and GEOSS applications than other more generic portals.

Services found through the ESG discovery functions are limited by the availability and the quality of the service, which depends on several factors, such as 1) the accuracy of observed data; 2) the quality of simulation models; 3) the quality of post-processing of information to provide the service; and 4) the reliability of the service.

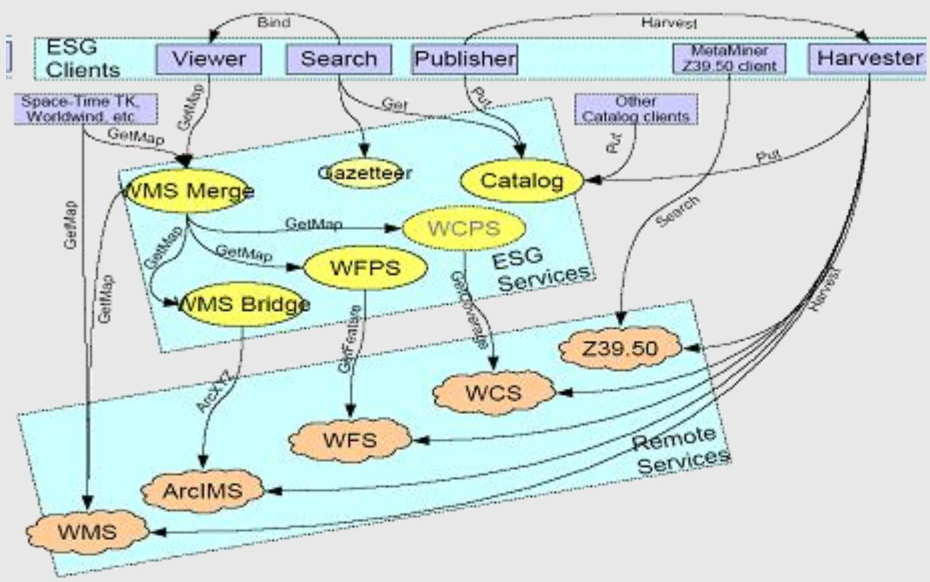

Figure 7.2. Web services chaining for the Earth Sciences Gateway.

In the context of the Alexandria digital library project, a research group around Terry Smith (1995) developed in the mid 1990s a first geoscientific processing workbench. Alonso (1999) continued this work and established with OPERA a programming environment that has become the tool of choice for the next ten years. While Smith and Alonso focus on the concatenation of functions (not necessarily GIS functions but also shell scripts, Java applets, etc.), others like Bennett (1997), Marr *et al*. (1997), and Jung and Albrecht (1997) focused on the development of process libraries. These are modules that represent physical or social spatial processes, encoded in some standard formalism such as a Stella™ model. Similar to Oliveira and Medeiros (2000), Liu *et al*. (2005) use a component-based approach to the definition of geo workflows.

Theirs is a more sophisticated implementation of the kind of tools that Marr and Albrecht used to define their process libraries. The problem with these implementations is that they employ highly customized, non-standard tools that decrease the likelihood of wide-spread use.

7.5. Geo-scientific workflows and process models

To address this problem, a coalition of researchers from the universities of Santa Barbara and San Diego, they developed a workflow system that now has the flexibility we were missing from Oliveira's earlier work. Based on a profusion of standards, the Kepler system (http://kepler-project.org) allows for the specification and documentation of a wide range of scientific workflows in distributed environments. Their work is in direct logical continuation of Smith and Alonso; Jäger *et al.* (2005) provide a nice application of Kepler for geoscientific workflows.

Case study 7.3 Kepler

In scientific workflows, each step often occurs in different software (ArcGIS, R, Matlab, RePast, C#). The Kepler scientific workflow system contains a wide variety of analytical components (e.g., spatial data functions and support for external scripts), allows direct (real-time) access to heterogeneous data, and supports models in many science domains.

Figure 7.3a illustrates some of the system's components using a trivial example. The Director controls the sequence of actor execution. Each actor takes data on its input ports, processes that data, and sends results to its output ports. Actors transform input tokens into output data tokens which then get passed to the next actor under control of the director (Figure 8.3b). Each workflow component is self-documenting as it is defined; the specification becomes automatically part of an ever growing component repository (http://library.kepler-project.org/kepler/ and Figure 7.3c). For scientists, this becomes a boon because such models can not only be easily shared but also referenced in published papers (Figure 7.3d).

Kepler uses hierarchies to encapsulate complexity (compare this with case study 7.1). Composing models using hierarchy promotes the development of re-usable components that can be shared with other scientists.

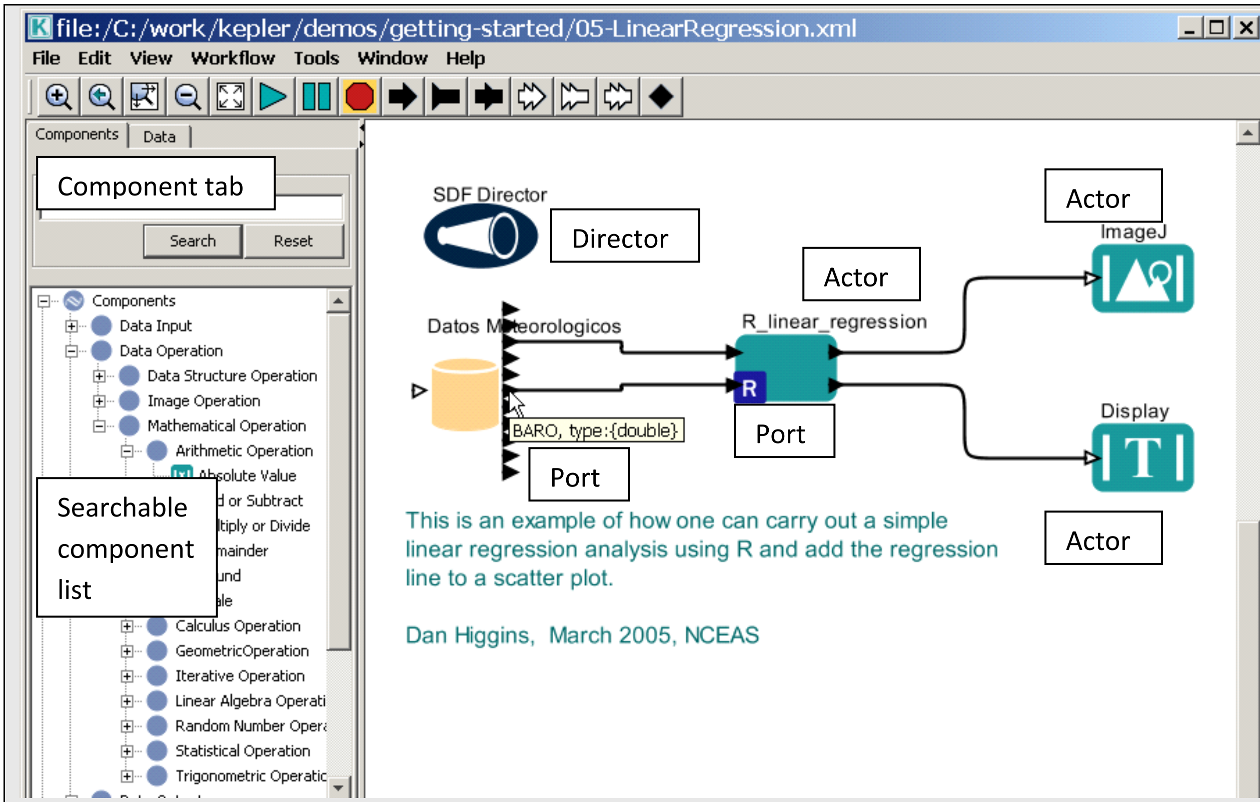

Figure 7.3a. Important components of the Kepler user interface

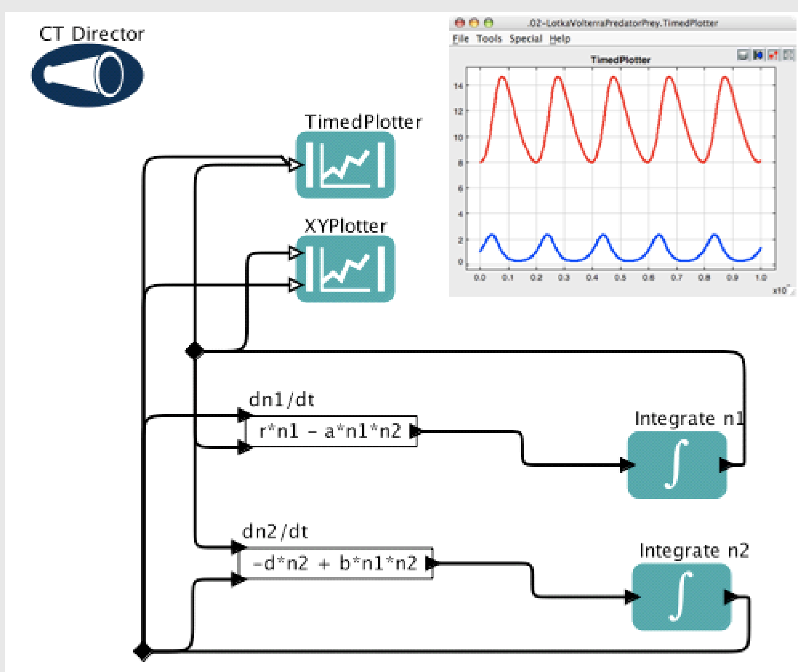

Figure 7.3b. Kepler execution is similar to Stella™.

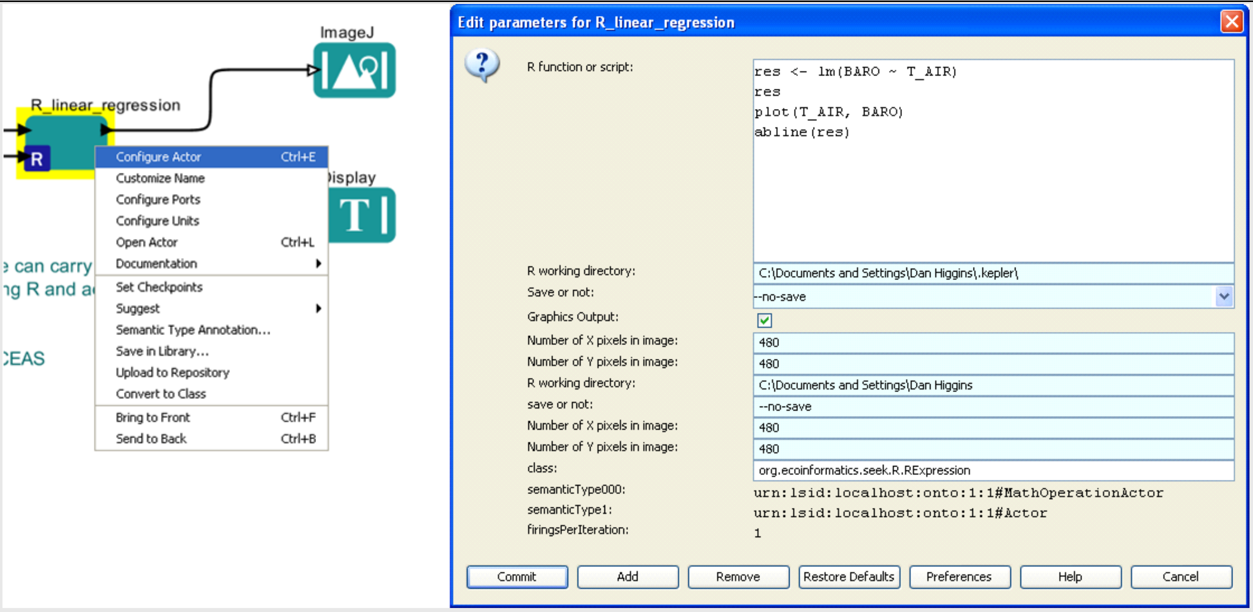

Figure 7.3c. Configuring a Kepler component may involve setting a number of parameters

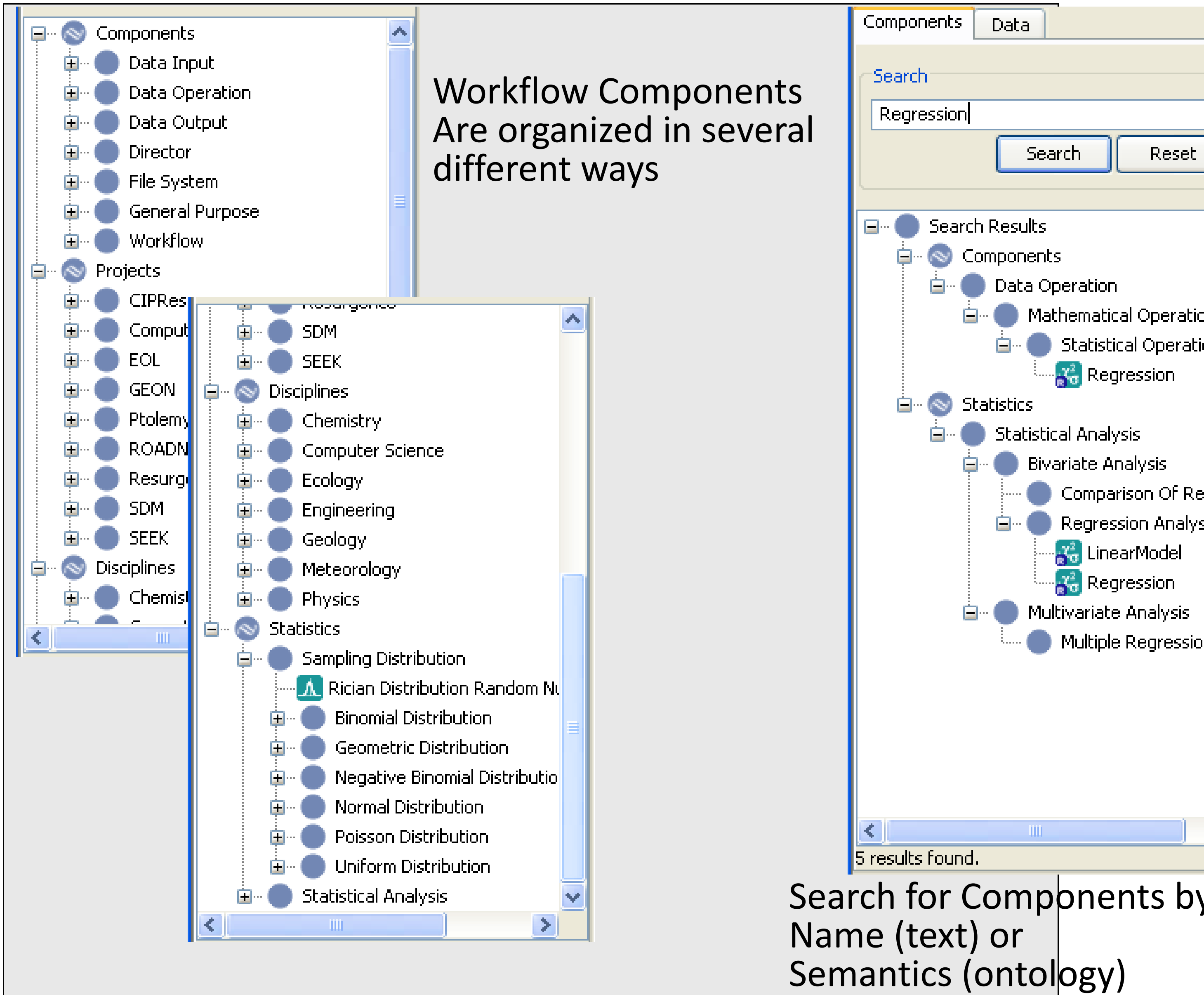

Figure 7.3d. Searching the Kepler component repository.

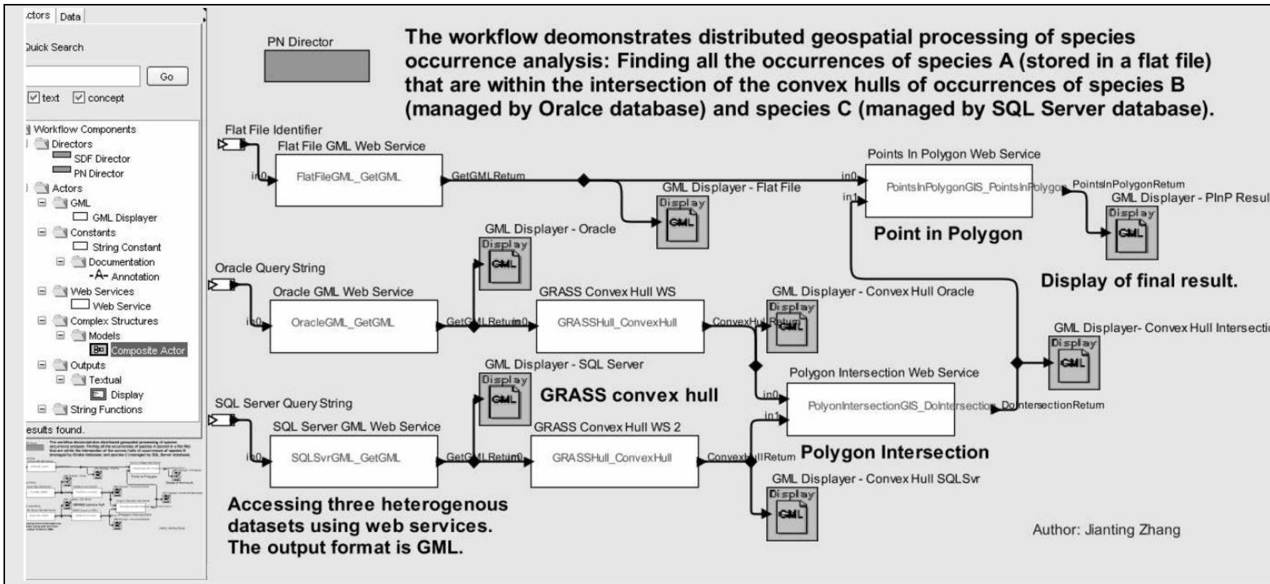

Figure 7.3e. Sample Kepler workflow modeling species occurrences.
(from Jäger et al., (2005), page 90).

7.6. Ontologies in support of application planning for the semantic web

One of the future-proof characteristics of Kepler is its adaption to GRID-based computing. Complementary to the work described in section 7.3.1, most academic GIS applications move now into an open source-based, distributed processing realm. The key to the success of such endeavors is the use of ontologies that allow formalizing conceptual models of spatial data and processes, which in turn are a pre-requisite to the mapping from one domain to another (Timpf 2001). At a fairly basic level, using a simplistic use case from a homeland security working group, Wiegand and Garcia (2007) develop a task-based ontology to search and combine data from different sources.

Medeiros' group (referred to in practically every section of this chapter), too, has moved towards web-based user interfaces. We already mentioned Baranauskas *et al*. (2005) attempt to solicit input from potential users of a web-based GIS. Schmiguel *et al*. (2004) contributed the analysis of user interfaces for web-GIS and Medeiros *et al*. (2005) describe a full-fledged workflow-based spatial decision support system in a web environment.

As mentioned before, ontologies are key to the discovery and the combination of web-based functionality. Lutz (2007) describes the use of OWL-S to formalize web services that can then be chained into workflows. His article illustrates how cumbersome it still is to (a) develop user interface service descriptions, (b) overcome the inflexibility of reasoning implementations, and (c) map between domain ontologies. At the same time, he shows the way to develop robust web-based GIS applications without having to resort to Kepler, which in the end is still a tool for the academic community rather than for end users.

7.7. Summary

GIS application planning (research) has changed dramatically since the early 1990s. Where traditional work involved cognition and reduction of user interface complexity, the emphasis is now on ontological tools that help to bridge between the inherent complexity of the software and the task-oriented conceptual model of the user. The same tools are also used to modularize GIS functionality to repackage it as workflows in a web-based environment. As such, HCI research has become mainstream, virtually undistinguishable from general software design.

7.8. Further reading

After reading this chapter, you should be curious to read Cai (2007) for its breadth and Lutz (2007) for its methodology and level of detail. If these wetted you appetite and you want more, then go for the very readable PhD thesis of Lemmens (2006). You may also want to keep an eye on the continued development of Kepler and its European counterpart Taverna. Finally, bookmark the web site of Claudia Medeiros (www.ic.unicamp.br/~cmbm/); her group has developed by far the largest body of work on HCI and GIS. If I were to advise a PhD student interested in GIS Application planning, I would send her to Campinas (near São Paulo), Brazil.

Revision questions

1. In a distributed cyber environment, what are the tasks that are common to all applications?
2. Does the phrase 'spatial is special' still make sense when we look beyond desktop GIS? Hint: the answer is yes, but the arguments have changed)
3. What is the role of the user in GIS application planning? Given the limitations outlined in this chapter, how can she be accommodated for?
4. What is the most important skill set for (a) a developer, (b) and academic interest in 21st century application planning?
5. How do mobile device change the game plan for GIS application development? For a first glimpse, browse the spatial application on the iPhone™ apps store. What works,

what doesn't? Can you identify major gaps in the provision of applications on this particular hardware platform?

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