Avakeeo[*] : the construction kit of computerised microworlds for teaching and learning Geography

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Abstract

This paper presents an innovative computer environment for aiding children in comprehending spatio-geographical matters, and supporting teachers in geography courses. It also provides a research experimentation platform for cognitive scientists and educators. Its design is based on modern software engineering techniques and is guided by research in two pertinent areas: computing in education and cognitive geography. The underlying issues introduced by each area and their implications on system design are discussed. Finally Avakeeo's functionality is described in detail from both a technical and usage viewpoint.

1. Introduction

That spatio-geographical matters possess a significant role in our everyday deeds and that there is a growing necessity for the development of the relative skills and abilities so that people could cope flexibly and effectively with the globalization of the cultural, economical and political surrounding landscape, constitute hardly deniable statements [16, 6, 33, 10].

On the other hand, geographers conclude that "common sense understanding and use of geographical information and spatial relations is error ridden, naive and very incomplete, resulting in misconceptions and misunderstandings" [17] and that "knowledge of the environment is incomplete, distorted, asymmetric, discontinuous, and imperfectly coordinated" [35, 12].

The fact that such shortcommings stem in part from the inherent complexity of spatial concepts, should not lead to downplaying the role of *education* in enhancing peoples' geographical reasoning (see for example [49]). Fortunately, geography education can take advantage of at least two recent advances:

a) The utilization of the computer as a tool in the teaching/learning process. It is broadly recognised that computers constitute a new "medium" which "like pencils and notebooks students use to think with", and that if utilised properly it can be of great educational value [44, 46, 43, 22, 24].

b) Research results in cognitive geography that were achieved in the context of the developing area of the Geographical Information Systems [17, 12, 31, 32]. From an educational point of view these new theories could be of great value as *learning* is largely determined by the individual's cognitive functioning.

While the latter should challenge educators to exploit the implications of the new findings on spatio-geographical cognition to education, the former constitutes the very purpose of this work: as engineers, we are concerned with the specification and design of computerised tools that would aid the teaching and learning of geography.

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[*] "Slate" in its Greek pronounciation.

To this end we first seek the requirements that are posed both by the educational side and geography itself as a curriculum subject. What are the characteristics and design principles of pedagogically accepted and effective educational software. Which are the spatio-geographical concepts that should be addressed? What skills need to be exercised and how? We refer to a number of studies concerning successful application cases of computerised tools in the classroom (for geometry, mathematics, geography, history, general expression) and to research on cognitive geography and draw out conclusions for the nature of the envisioned tools.

Next we design the software to fulfill those requirements; after evaluating existing systems that have been developed for similar needs, we provide "Avakeeo" a kit for constructing "geography microworlds" by means of modern software engineering techniques. Microworlds, are suitably crafted educational applications requiring the active participation of children, who step by step build up their geographical knowledge and skills through experimentation and play.

The contribution of this work, which is part of a long-term project[*], is that it proposes an alternative to already existing learning environments by exploiting state of the art information technology, together with a methodology for the systematic production of exploratory software for geography. Besides teachers, researchers (geographers, psychologists) could adopt Avakeeo as the suitable workbench by means of which they could test assumptions on spatial cognition and experiment with various ways of communicating geographical knowledge.

The paper is organised as follows: Section 2 sets up the framework for the development and use of computerised tools in education, which is adopted throughout the current work. Section 3 investigates the nature of the targeted software as far as its geography-specific features are concerned; in doing so it examines a number of aspects regarding spatio-geographical perception and draws implications about the corresponding requirements posed by a geographical point of view. Based on the discussion of the two previous sections, section 4 provides a specification of the envisioned "courseware", while section 5 addresses the question of how this software is going to be developed not by "programmers", but instead by the end-user community: educators, geographers, teachers, and of course children. After briefly surveying some existing systems that were developed to address similar needs, it introduces "Avakeeo" and the main concepts behind it. Section 6 provides a detailed overview of the system while section 7 gives some examples of how Avakeeo could be utilised in the classroom. Finally section 8 discusses the current status of the system and some future plans and section 9 summarizes the conclusions.

2. Microworlds[**] in the curriculum

Since its debut as an educational tool, the computer's role varied widely as its usage reflected different teaching methods and principles, evolving from simple drill and practice programs to presentations and guided tours, to intelligent tutoring systems, to simulations, to special purpose computer languages [26] and to interactive learning environments [43, 45]. While there is still much ongoing discussion concerning the nature and usage of pedagogically-proper software, experience from successful application cases indicates that if microworlds, are to be really beneficial they should:

- … engage children in active exploration, interpretation and construction of ideas and products, leading children through question and experiment to the discovery of the underlying facts and relationships [16, 21],

- … encourage and give children the opportunity to learn by doing, by building and manipulating artifacts [43],

- … provide children with challenge, with novel experiences, engaging them in real tasks in which they have some personal interest and investment ,

- … provide children with rich information and quality materials [21],

[**] See [11] for an extensive discussion on the usage of this term.

- … lead children to formalize intuitive ideas by expressing them with the use of symbols, test them on the computer and immediately observe their effect, thus achieving a merging of intuitive and reflective thinking [27],
- … offer children the capability of creating new entities and experiment scenarios on their own, usually through "programming" mechanisms, either verbal or visual ones [13],
- … allow for more than one representation of the underlying entities letting children use them interchangeably at will [11].

Taken as general guidelines these points laid the context of the educational uses that the envisioned tools should fell into.

3. Geographical concerns

Throughout the literature we find a number of cases where computers have been used in a variety of ways for geography education: simulations of geophysical phenomena, simple GIS-like applications, simulated globes, spreadsheets for statistical analyses, map drawing packages, multimedia navigations and others [for example see 30, 18, 42]. Most of these are good examples of how geography courseware could look like but lack the systematic approach of a development methodology that we pursue.

In order to gain an understanding of the nature of the envisioned microworlds as far as their geography-specific features were concerned, we turned to examine some of the cognitive aspects of spatio-geographical reasoning [20, 12]. This effort was based on the premise that if we are aware of the involved cognitive then we stand in a better position to devise methods for communicating the relevant concepts to students on the one hand [47] and on the other, to design suitable software tools with which to represent and manipulate those concepts [50].

In this context, some of the key considerations that should be taken into account in the design of geography microworlds are the following:

- The experience of geographic space is not homogeneous, but varies with scale [9, 17, 32]. Different categories of space can be distinguished according to the means and cognitive level of their perception as well as the functions that are involved in the understanding and mental manipulation of each one. What follows, is that children could be stimulated to think in terms of, and about all space categories. Further, they could be taught to flexibly switch their thinking among them and translate geographic concepts from one space category into another. Such transformations provide new mental perspectives and facilitate the comprehension of the relative spatial properties.

- Irrespective of scale, any environment involves a number of spatial components [17]: Location of occurrences, spatial distributions of phenomena, regions of bounded areas of space, hierarchies or multiple levels or nested levels of phenomena, networks of linked features, spatial associations, and surfaces of generalizations of discrete phenomena. Children could become aware of these spatial components and of their inter-relationships. They could be taught how to identify them, and induce the implied semantics, as well as how to recognize, apply and manipulate fundamental spatial concepts such as nearest neighbor or distribution and region membership.

- Perception of space is in most cases dominated by the visual sense [32, 34]. A number of visual cues such as atmospheric perspective, height in plane, relative size and focus, guide our everyday spatial perception. Children could be trained to identify and effectively utilize environmental cues. Moreover, they could learn to see and draw perspective's spatial cues and translate orthographic views into perspective ones. Such exercises greatly heighten the awareness of the structure and form of spatial configurations and, as a sound example of visual thinking [34], provide a vital and creative complement to the linear operations built into our language.

- Information about the environment is understood only as it is relevant to the goals, needs or psychological state of the individual at a given moment; human intentionality and purpose are factors which greatly influence the understanding of geographic space [9]. Children could be guided to actively think about their environment under different perspectives and through different contexts. Spatial reasoning will switch accordingly, and through the combination of the different observations an integrated understanding will be achieved.

- Spatial perception is not the perception of space as such but of the relationships between the objects within [7, 34]. The representation of spatial configurations takes the form of structural descriptions specifying the relations among the critical spatial components with respect to a frame of reference. In forming such descriptions children may have difficulties in choosing the suitable spatial relationships if certain spatial concepts have not yet been sufficiently elaborated. Geography courses could address such weakness and provide exercises for the comprehension of spatial relations such as: left of, right of, beside, above, below, behind, in front of, near, far, touching, between, inside and outside [32]. The greatest difficulty that children face, concerns the establishment of appropriate reference frames [7]. They either fail to apply systematic frames of reference, a vital prerequisite for tasks such as map reading, or to utilize multiple reference frames of different kinds (egocentric, allocentric, coordinate), or to translate among them.

  Suitable scenarios should be devised that confront children with situations that exercise such abilities. For example, experience with Logo-based microworlds that enabled children to navigate a "turtle" on the computer screen, by adopting various frames of reference at will, showed a gradual shift from utilization of strict egocentric to coordinate reference frames without any special guidance or difficulty: "using analytical cues…was rather a matter of learning the rules of a new game" [26].

- Geographical understanding is deeply shaped by culture. Differences in spatio-geographical cognition that stem from different cultural backgrounds, are usually projected to variations in the relative verbal expressions. Examples include variations of the use of prepositions in locative expressions, and the adoption of "unusual" reference frames by people on many islands, as discussed in [31]. From a pedagogical viewpoint this observation indicates that geography teaching can be more effective if it feeds on the cultural background of the students [39], in other words microworlds should be customizable to the different school contexts.

Moreover, geographical understanding goes hand by hand with the development of specific abilities and skills such as [17]:

- Map reading (which basically involves symbol identification and orientation), and map sketching (which involves the ability to integrate information about landmarks and routes into an organised whole contained within some bounding scheme or frame of reference [2]).

- Direction giving and following (which involves image and verbalization of memory), and the ability to give and comprehend directional and distance estimates as required by navigation [2, 48].

- Way finding and navigating, which involves spatial sequencing, path integration and short-cut procedures.

4. Geography Microworlds

Based on the guidelines discussed in the two previous sections we can now derive the key requirements that geography microworlds, the "Geoworlds", should meet. In particular, Geoworlds should:

a) Allow the visualization and direct manipulation of geographic phenomena and spatial relationships and components in multiple geographic scales. Geoworlds should enable children to study and step by step direct simulations, relating to both large-scale spaces such as the sun-earth-moon motion and to small-scale spaces such as a forest fire on a local mountain. Children could observe the interdependencies and comprehend the mechanisms of the evolution of phenomena, experiment with what-if scenarios by altering parameters, or perform GIS-like operations such like producing thematic views, issuing structured queries, and so on.

b) Allow the construction and manipulation of landscape models and maps, in two and three dimensions. Geoworlds could for example, provide children with the means to join environmental "components" and build models of virtual areas under the guidance of a system maintaining the spatial integrity, translate between perspective and vertical views, rotate, transform and spatially manipulate the models. Further they could produce various kinds of maps and realize virtual walk-throughs in a 3D environment under some specific inquiry that the scenario indicates utilizing a number of navigation and metric tools that will be offered.

c) Allow the concurrent display and manipulation of multiple views of the same phenomenon or simulation. This would stimulate the appropriate conceptual links and the comprehension of relevant metaphors.

d) Provide a framework of Logo-style programming (commanding) [26], applied on landscape layouts and maps. Scenarios could be set up where children would navigate "rabbits" (metaphors of their body on the map) through a set of suitably chosen commands (their definition and usage implying elaboration on spatial concepts and relations), to drift around with the purpose of achieving some specific goal indicated by the scenario. Again, scenarios could address various geographic scales, from cross-continent trips (for example re-creations of famous discovery missions), to in-town ones (where the mission could be to lead the rabbit through the "best" path to exit the town). Interesting variations could be devised by providing qualitatively different sets of available commands that children could utilize, or by allowing the use of either a single or several different frames of reference for children to be based upon.

e) Provide access to various kinds of associated multimedia information. Geoworlds could benefit by libraries of rich material of texts, pictures, photographs, videos, maps, narrated annotations, etc. and create attractive presentations. For instance, a scenario could present children with a number of photographs of the local surroundings, then proceed to abstractions of those images to graphic layouts that could be geometrically studied and manipulated and finally reach the construction of maps, thus achieving a smooth and comprehensive conceptual transition.

f) Provide the means for the composition of multimedia documents. Geoworlds could be designed that would ask children to write compositions describing their experiences from virtual trips, annotating them with pictures, referring to maps or drawing figures, and thus providing a medium for the synthesis of a number of ways of expressing spatial knowledge.

g) Support collaborative work between students. A possible scenario could allow one team of children to build landscape models while another team would navigate rabbits and search around for some hidden "treasure" in that area. Another scenario could allow a number of children to navigate different rabbits (from individual stations) in order to meet some common goal.

5. Geography-specific reusable components

There is a key issue that has been so far left untouched: "who is supposed to develop the required microworlds and how"? Always in the framework for microworld construction and use that was laid in section 2, *end-users*, that is educators, teachers and students, should be given access to the same constructs and tools that were used to build a given Geoworld so that they could alter, tailor or build it from scratch [22], according to their own needs.

A number of systems like Logo [26], Boxer [45, 46], Hypercard and Toolbook [4] are build around this concept (based on radically different approaches), providing the workbench for the construction of microworlds. In systems like these, the user has to model a situation, represent the involved concepts by utilizing each system's primitive constructs and define a microworld's behavior in terms of a procedural language. Although this method is enough to cover a number of educational goals, in cases where the requirements of the targeted microworlds raise to more than mundane -just like in Geoworlds- the process of their development sooner or later reaches the following impasse:

- either teachers and children find themselves spending much more effort constructing what is to be studied, than really studying it, or
- a "programmer" is inevitably involved to carry out the job, who finds him/herself in a cumbersome programming environment that cannot satisfy the development requirements of even medium complexity projects -as it is not designed to do so.

This situation typically results in low-end microworld functionality[*], poor designs, big development costs and largely unreusable software. Avakeeo tries to alleviate these deficiencies while retaining the desirable characteristics of those systems. To this end it

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[*] Although it should be stressed that even a "low-end" microworld could be of great educational value.

follows an alternative path: the Geoworld developer is provided with a kit of high-level, geography-specific reusable constructs each with predefined behavior, together with an assembly mechanism that allows the interconnection of any required modules into functional Microworlds. This "library" of prefabricated constructs is meant to be constantly expanding by new entities developed by "programmers" according to requirements indicated by specific educational needs.

Thus Avakeeo demonstrates two distinct faces: one to the non-programmer end-user and another to the experienced programmer. The former is simple, obvious, intuitive and still powerful; the latter is efficient and familiar to its audience. Many of the design ideas have already been exemplified in educational environments like Rehearsal-world [15], Cabri-Geometrie [28], Playground [14], Lego-Logo [41], and Agentsheets [40], as well as in other systems from the fields of user-interface design and software-engineering like ThingLab [8], ConMan [19], Fabrik [23], Conic [25], Vista [38], SAOS [36], and PARTS [29].

Central to Avakeeo's architecture is the notion of the ready-made basic building blocks, the "bricks", that form the raw material for the construction of Geoworlds. A component's design should be generic enough to capture an abstraction of its multiple individual instances and accommodate the diverse needs of the various contexts in which will participate. Indeed, providing the suitable reusable components in systems that adopt a "component-oriented way of development" has proved to be "a problem that is an order of magnitude more difficult than that of developing a single, specific application" [37].

Which are the necessary geography components? Breakdown of the functionality of the envisioned Geoworlds into separate modules, lead to the design of a number of reusable "chips", the GeoChips, some of which are presented in Appendix A'. These comprise a starter set that could realize a series of interesting Geoworlds and demonstrate the concept and functionality offered by Avakeeo. GeoChips are designed to be simple in functionality, consistent in user-interface issues and comprehensive to end-users providing the minimum number of required features. Their power lies in their cooperative ability.

6. Avakeeo overview

End users can use, customize or construct new Geoworlds from scratch using pre-fabricated Geochips, like the one depicted below.
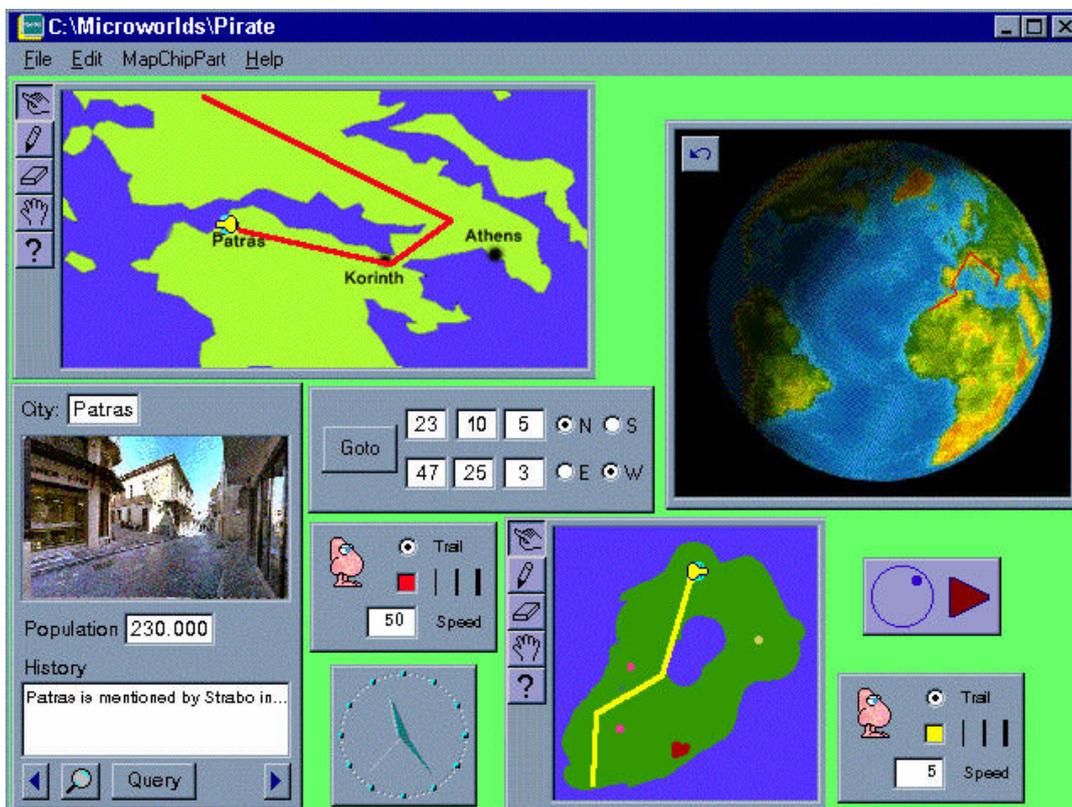

Figure 1. An example Geoworld display

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In this example children are in the search of the hidden treasures of a pirate who during the last century traveled all around the world leaving behind cryptic evidence on where exactly his fortune was hidden. Starting with an incomplete and vague map children can utilize a number of tools throughout their course: a globe and contemporary maps upon which tiny "rabbits" can travel along under children's commands, clocks and geography-encyclopedias containing valuable information about places they visit, and special purpose views that display what a rabbit's "eyes" see. Notebooks are also available for keeping notes and other relevant information that children find along. Their task is not at all easy, in fact it could well expand to the whole semester!

GeoChips are autonomous but cooperating applications each with its own user-interface, functionality and logic and can be positioned anywhere on the screen. The GlobeChip rotates the earth under user's commands providing a number of views under different perspectives, MapChips display Maps under selected thematic categories, BookChips (like the one at the bottom-left) provide browsing and editing capabilities to multimedia information accompanying the maps, ClockChips can show or set the time and so on (see Appendix A').

The interesting thing is that GeoChips work in concert, each one depending on or providing information to others according to their "linkage", as it is defined by the Geoworld developer (see below). Interactively manipulating any part of a GeoChip's user-interface would result in changes to every other GeoChip that is linked with the former. In the above example, the two RabbitCommanderChips (see Appendix A') provide movement commands to the RabbitChips which, after processing these commands, inform the corresponding MapChips about their new positions, and the latter update the displayed rabbit paths. At the same time the BookChip, triggered by its relative MapChip, automatically "turns" its pages and displays any relevant information to the rabbit's position on the map.

Geoworlds like the above are realised by utilizing a pool of prefabricated GeoChips which are developed by "programmers" under requirements stemming from specific pedagogical or geography-related needs. GeoChips can be incorporated as many times as required to the Geoworld under construction. A special purpose visual editor allows the end-user (Geoworld designer) to define the functionality of a Geoworld by establishing suitable data-flow links among GeoChips so that they can share information and coordinate their behavior. Data exchange is performed via each Geochip's "Pins", which realise the necessary input/output communication channels and protocols.

A GeoChip can have as many Pins as required. Each Pin has a name, a shape (signifying its connectivity capabilities) and a color (signifying its data-type). Links can be established between Pins of the same color and matching shape. The next table lists all available Pin shapes.

Single Output. Allows a connection to be established with one other Pin for data exports	*<pin name>*	*<pin name>*	**Single Input**. Allows a connection to be established with one other Pin for data imports
Multiple Output. Allows multiple connections to be established with many other Pins for data exports	*<pin name>*	*<pin name>*	**Multiple Input**. Allows multiple connections to be established with many other Pins for data imports
Single Input/Output. Allows a connection to be established with one other Pin for data exports and/or one other Pin for data imports	*<pin name>*	*<pin name>*	**Multiple Input/Output**. Allows multiple connections to be established with many other Pins for either data exports and/or data imports
Multiple Input, Single Output. Allows a connection to be established with one other Pin for data exports and/or multiple connections with many other Pins for data imports	*<pin name>*	*<pin name>*	**Single Input, Multiple Output**. Allows a connection to be established with one other Pin for data imports and/or multiple connections with many other Pins for data exports

Table 1. List of available Pin shapes (regardless of color).

The following figure exemplifies a Geoworlds's link definition process. Geochips display their Pins and the user establishes the required connections by drag-and-drop actions.
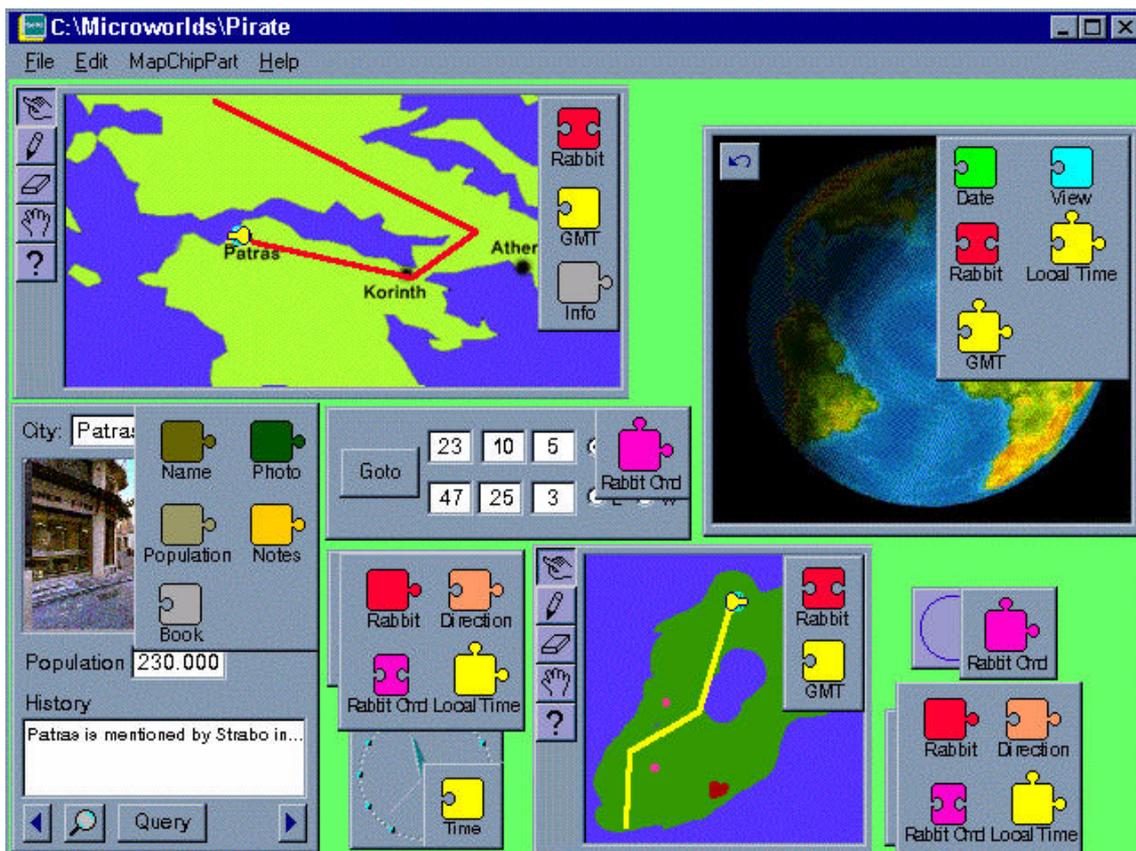

Figure 2. Example of GeoWorld-link definition phase.

The following links are defined to achieve the Geoworlds functionality as it was described earlier. Note that not all Pins need to be connected; just the ones required by the desired scenario.

Chip	Pin	to	Pin	Chip
RabbitChip (red trail)	Rabbit	->	Rabbit	MapChip (Greece)
RabbitChip (red trail)	Rabbit	->	Rabbit	GlobeChip
RabbitChip (yellow trail)	Rabbit	->	Rabbit	MapChip (pirate)
Goto-CommanderChip	Rabbit Cmd	->	Rabbit Cmd	RabbitChip (red trail)
Go/Turn-CommanderChip	Rabbit Cmd	->	Rabbit Cmd	RabbitChip (yellow trail)
RabbitChip (red trail)	Local time	->	Time	ClockChip
GlobeChip	GMT	->	GMT	MapChip (Greece)
MapChip (Greece)	Info	->	Book	BookChip

These connections are not explicitly displayed on the screen for clarity reasons. The user can easily inspect each Pin's links on demand.

What makes a Geoworld "run"? As soon as a GeoChip senses a new data value in one of its Pins -which is propagated by another Pin of one of its linked GeoChips- it responds by recalculating its state on that new condition. This may have the result of changing the display for example and/or other internal values some of which may be exported via corresponding Pins and in turn affect other linked GeoChips and so on. In that way a "trigger" is propagated throughout a web of linked GeoChips each of which reacts accordingly and participates in the "run". Changes in a GeoChip's state are initiated by the

user manipulating controls of the user interface or by "active" GeoChips emitting values at specific time intervals.

7. Avakeeo in use

Some Geoworld scenarios that could be realised with Avakeeo and demonstrate its utilization are given below.

1. Traveling, route planning, map reading, comprehending spatial directions.

   a) Children are provided with world-Maps accompanied by relevant Books, together with informal descriptions (textual, narrated, pictorial) of well-known explorer's paths (Magellan, Great Alexander, etc.), and are asked to re-create them by suitably commanding the rabbits.

   b) Children are asked to realize inter-Europe trips. They are provided with road/railway Maps, time and fare tables, and are assigned to reach specific places under various constraints: reaching each place at specified times, spending no more than a given amount of money, using trains/buses/planes only, etc.

   c) Children are provided with a city-Map and are given a postman's role: they have to deliver letters to specific addresses, by following the "best" paths (shortest time or distance, most beautiful path, etc.).

For scenarios like the above, children would utilize the GlobeChip, the MapChip, the RabbitChip and the various RabbitCommanderChips, the CalculatorChip and the BookChip and should come up with a rabbit command-script, together with a Book containing a composition of their findings and observations along the trip.

2. Map design, surveying.

   a) Children are provided with informal description of a place made by a traveler (landmarks, spatial relationships, metrics, etc.) and are assigned to sketch a map of it. Then they should compare their map with an original one.

   b) Children are provided with a 3D map of an area and are asked to sketch the corresponding 2D map after making observations on the 3D model.

Here children could utilize the MapEditor and rabbits (through the RabbitChip and the RabbitCommanderChips) that would travel along the Map under construction and the 3DMapChip to realize the fly-abouts of the 3D areas.

3. Location selection, spatial planing.

   a) Children are provided with bare Maps of an area and are asked to find suitable places for settlement of cities or villages (after examining factors like vegetation, water, safety, trading routes, etc.), draw road networks and mark the locations for public buildings (schools, hospitals, factories, etc.).

   b) Children are asked to find places that resemble their home-place.

For such scenarios, children would use the MapChip and the BookChip to make suitable queries on the corresponding Books and Maps.

4. Spatio-temporal relationships.

   a) Children use the SunEarthChip together with the GlobeChip and a number of rabbits that are positioned around the globe, to experiment and make observations on time-space relationships among different places.

   b) Children use the GlobeChip, the HorizonChip, the MapChip, and the ClockChip to re-create Eratosthenes method for measuring the circumference of the earth.

8. Current status and future work

Avakeeo is currently being implemented based on the OpenDoc [1] specification for component-oriented development, using C++ for both the Macintosh and Windows platforms.

Future work involves:

   a) Ability to reuse a constructed Geoworld as a complex GeoChip, i.e. as a basic building block for the construction of other Geoworlds, thus equipping the end user with

the power to extend the pool of reusable chips by (her)himself. Such a feature would of course greatly enhance the scope of the system.

b) Provision of inter-workstation GeoChip-links that would support groupwork among student-teams. A rabbit path on a world-Map for example that is produced by children in a Geoworld running in workstation-A could be exported to another Geoworld in workstation-B and be used according to the scenario of the latter (be fed in a GlobeChip for instance).

c) Enhancement of a Geoworlds programmability with a special purpose scripting (procedural) language by means of which participating GeoChips could be instructed to perform specific actions in a serial manner.

d) Extension of the pool of primitive components by developing further more GeoChips that would cover additional aspects of geography and even of other subjects like geometry, mathematics and history. Hardware GeoChips (like real globes for example) could also be implemented which, following the same construction rules as the software ones, could "connect" to the latter and form hardware-software Geoworlds.

e) Application of Avakeeo in real classroom conditions. Being the ultimate target of the overall enterprise that will corroborate (or not) our expectations, this undertaking is scheduled to take place in a relative project in cooperation with public and private schools and the support of major consulting agencies of the Greek Ministry of Education.

9. Conclusions

This paper is concerned with the conception and design of Avakeeo, a software toolkit intended to be used by students, teachers and researchers to support the study, teaching and experimentation of spatio-geographical issues. This work was inspired by the belief that well founded *education* is the key to the promotion of people's geographical understanding and related skills and has build on the premise that *computers,* when properly used in an educational context, could play major role towards this goal. On tracks laid by research concerning the utilization of computerised tools for educational purposes we investigated the nature of the geography-specific software in the light of research findings in cognitive geography. These are taken as a valuable guide dictating a number of aspects involved in spatio-geographical thinking that should be taken into account while designing geography-specific courseware. Applying the resulting implications under an engineering point of view we came up with specifications of framework applications, each defining a class of a large number of individualised "Geoworlds".

Next, and following a major requirement that stems from the educational side dictating that Geoworlds should be constructed by end-users and not by "programmers", we provide Avakeeo as the vehicle to do so. By adopting modern software engineering techniques Avakeeo introduces a new methodology for the development of educational software redefining the roles of the technical and creative contributors: engineers develop "components" that teachers and children use to "assemble" applications on their own. These reusable "bricks" are designed after careful breakdown of the various categories of desired Geoworlds into individual functional modules which can either autonomously or in conjunction with other such modules be utilised in more than one situations. Geoworlds are conglomerations of suitably "connected" predefined functioning parts that we call "GeoChips".

As a bootstrap we designed the set of GeoChips presented in appendix A', each one addressing specific pedagogical and/or geography-imposed requirements. Interesting Geoworlds like the ones outlined in chapter 8 can be attained by properly synthesizing those GeoChips. Of course there will be a lot of new ideas and additional requirements for the construction of new GeoChips even from the early uses of the system; and they could be all accommodated as Avakeeo is mainly a methodology and design concept, rather than a narrow-scope authoring environment.

Acknowledgments

Appendix A': Description of basic GeoChips

This appendix provides an outline specification of a starting set of GeoChips that were designed to demonstrate the system's functionality. Each description includes a snapshot of the GeoChip's user-interface and the set of its Pins.

- **SunEarthChip:** Animates earth's motion around the sun. The user can select between a top view or a perspective one that provides 3D animation. Motion can be continuous or step-wise. The user can drag the earth along the ecliptic and change the reflected period of the year.
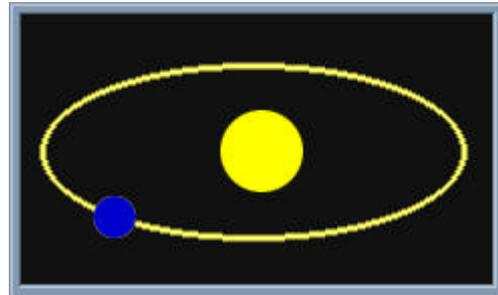
Date — Reflects the day of the year that corresponds to the position of the earth on the ecliptic. When set by another GeoChip, the earth is position accordingly on the display. If the earth is dragged by the user, the Pin emits the date that reflects the new position.

- **GlobeChip:** Animates earth's motion around its axis. The user can initiate or pause the animation which is made-up of snapshots produced by 3D modeling tools. GlobeChip features the following Pins:

**Date** — Displayed globe inclination reflects the value of this Pin.

Local Time — Corresponds to the local time of the area that is at the center of the current view. Switching to another view changes the value of this Pin.

GMT — Reflects the local Greenwich time. Changing the value of this Pin (from another GeoChip), forces the GlobeChip to rotate the earth so that the new value is consistent with what is displayed. Similarly, by rotating the earth via the user interface results in constantly updating the value of the Pin so that consistency is maintained.
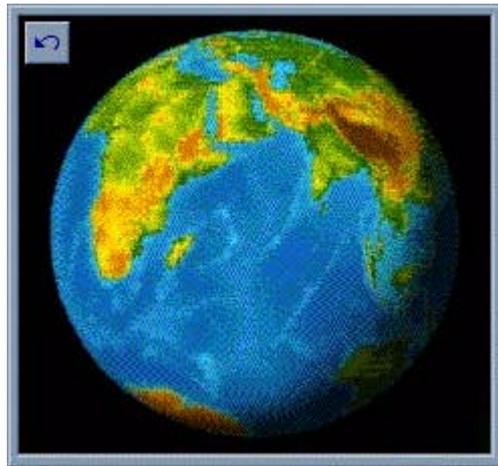
Rabbit — Through this Pin, one or more Rabbits can be positioned on the earth and walk-about under user's commanding (see "RabbitChip" below).
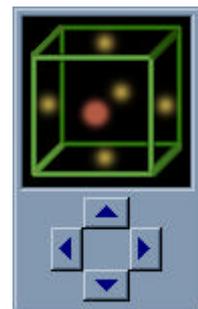
View — Directs the viewer's position in space (see next Chip description).

- **GlobeControl:** When connected to a GlobeChip it allows the user to fly-around the earth by changing the viewing position through user-interface controls. It provides a:
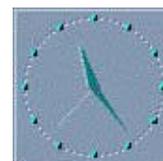
Viewer's Position

• **ClockChip:** Displays a given time. The user can set the clock to a new time by dragging the clock's hands.

Represents the displayed time value. If another GeoChip changes this value, the display is updated and conversely as the user changes the time through the user interface, the value of the Pin is updated.

• **RabbitChip:** Rabbits are the globe-trotters that can be linked to Maps or to the Globe, and drift around by following the user's movement commands. Rabbits can walk, or fly, or sail, or drive, (or all of them) at a given speed. While traveling, the rabbit can leave a trail (or not) of a specified color. Its Pins are as follows:
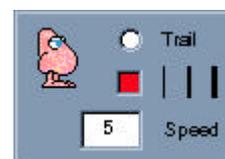
Exports the rabbit itself. Through this Pin a RabbitChip is plugged on MapChips, and the GlobeChip.

Movement commands, issued from other GeoChips (see below), are input and processed.
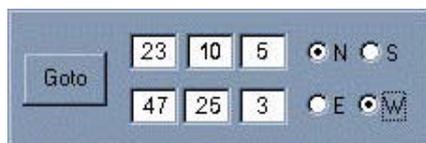
Reflects rabbit's current direction. It can be set externally (from another linked GeoChip), or as a result of the execution of a "turn" command (see below).

Exports the local time of the current rabbit's position.

• **RabbitCommanderChip(s):** They provide the means for issuing movement commands to Rabbits. The reason that rabbit commanding is spread to more than one GeoChips is that each of these refers to a specific aspect of two types of reference frames (Cartesian, egocentric), and thus selective usage can be obtained as required by a given scenario. RabbitCommander chips include:
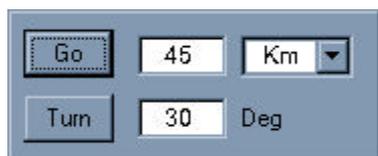

• Used to position a Rabbit in an absolute lat/long location. Exports a lat/long position in two alternative formats:

RabbitCmd   Earth Position

• Used to instruct a Rabbit to proceed on its current direction or turn to a new one, with reference to its current position and orientation. Provides:

RabbitCmd

• Another type of RabbitCommanderChip, comprises of an interpreter through which single commands or whole programs of rabbitCommands can be edited and issued to a RabbitChip. A representative set of supported commands includes the following:

Go <x> <metric units>

Go until <distance> from | after <location>|<landmark>

Goto <location>|<landmark>

Turn left | right | <angle>

Turn to <direction>

Follow <path>

• **MapChip:** It is the main tool for studying Maps. Various collections of Maps are supposed to be found in Avakeeo, and can be selected for browsing. The user can zoom in/out and/or select specific portions of the displayed map (through controls not shown here). Rabbits can be positioned on the map and navigated through the mechanisms that were described earlier. Other accompanying

GeoChips (that are not yet fully specified), can plug to MapChips and in conjunction with RabbitChips and BookChips (see below), allow for complex queries on maps (of the type commonly found in GIS applications). Map's Pins include:
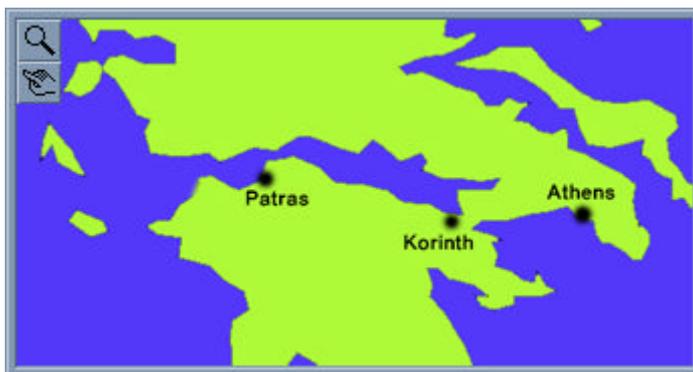
 As many RabbitChips as needed can plug to a MapChip through this multiple input Pin. As rabbits move about, their paths are updated on the display.

 A Map is synchronised by a GMT source so that Rabbits can time their movements.

 Through this Pin a Map provides access to relevant multimedia information concerning the geographical features of the represented area.

• **BookChip:** Allows browsing and general manipulation of Books, displaying one page of multimedia data at a time. With the aid of a number of accompanying GeoChips (not yet fully specified) the user can filter out certain pages that meet specific criteria, or even issue complex database-like queries on a Book. The user can also create new Books by defining the layout of groups of pages, the kinds of data that should be hold, and so on, in a process similar to that of defining a database schema in a DBMS.

A BookChip, exports through its Pins any piece of data that a page can hold (see for example figure 2). These multimedia data can serve as inputs to other GeoChips as required: for example, video-clips of specific pages could be provided to a TVChip (see next) and be played-back when these pages are somehow being selected.
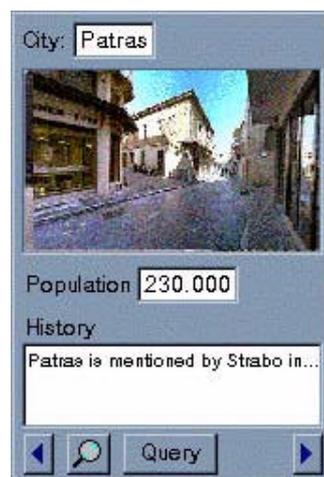
• **HorizonChip.** Displays the sun's trajectory on the horizon at a given date, and the sun's position at a specific time within that day, at a specified place and orientation on the earth. By dragging the sun on its trajectory the user can affect the local time, thus changing the corresponding Pin's value.
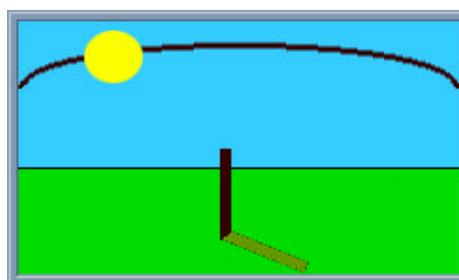

• Other Chips. **TVChip** and **RadioChip** displaying static or moving pictures and playing sounds as are input through their corresponding Pins. **CalculatorChip** implementing a simple spreadsheet. **MapEditorChip** providing the necessary tools for the construction of Maps. **3DMapChip** providing views to 3D-land models, allowing the rabbits to fly-about the corresponding areas.

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