Visualisation of route descriptions in a resource-adaptive navigation aid

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In our current research project REAL, which is part of the special research program 378 \`Resource adaptive cognitive processes‘, we are building a resource adaptive navigational help system. The system can generate multi-modal graphical route descriptions for different output devices, and has the ability to adapt to various restricted resources during the generation of graphical route descriptions. The generation and presentation of those descriptions in navigational tasks within an airport scenario constitutes the domain, where we are investigating the relation between spatial descriptions and their cognitively adequate visualisation. In order to help the addressee to build a cognitive map of the environment we developed different graphical visualisation techniques for route descriptions. These techniques cover the whole range from simple static black and white sketches to 3D animations through a virtual environment guided by a virtual presenter. In addition to the visualisation techniques reported here, we will introduce our ideas to visualise path relations adequately during the presentation of a virtual journey. These ideas are based on experiments reported by Zimmer, Speiser, Baus (2001), where they investigated the characteristics of path relations described by the german path prepositions (e.g. vorbei (past), entlang (along)). The experiments rose evidence that there are protoypical characteristics of trajectories for different path relations depending on the reference object's shape. The computational model will modify the trajectories according to the shape of the object. Parameters can be adjusted in order to approximate the prototypical trajectories, which were observed in the experiments. Our working hypothesis is that the modified trajectories visualise the different characteristics of path relations most adequately by adhering to the prototypical paths as far as possible.

1. Introduction

In the project REAL, we investigate the design of a resource adaptive navigational help system with the capability to adapt to various restricted resources (on a cognitive or a technical level) during the generation of graphical route descriptions. We generate images/animations for different classes of output devices ranging from a high-end 3D-graphics workstation to a personal digital assistant. Therefore, we have to deal with different and limited technical resources, but we must also take into account the user′s limited cognitive resources when decoding and understanding the presentation. On a 3D-graphics workstation, such a description can consist of a 3D-walkthrough guided by a virtual presenter performing pointing gestures, and can also incorporate meta-graphics accompanied by spoken or written text in order to describe the route itself and relevant elements of the environment (see Figure 1).

Figure 1 about here

We can present the resulting animations from different viewpoints: For example, we can start the presentation in a birds-eye view of the scene in order to give an overview of the entire trajectory, and we can then zoom in order to follow the route in an egocentric view of the scene. In case of time pressure the presentation will speed up, and the system will reduce the amount of detail presented in the virtual walkthrough, e.g. omitting the virtual presenter′s visualisation. This reduction of detail also helps to address time critical situations by not burdening users with very long and detailed directions, which would be very hard to memorise and to follow correctly when in a hurry. The lower end of graphical representations consists of simple sketches of the environment and arrows indicating the direction.

In addition to presentations at a stationary information booth, we are also considering information presentation for mobile systems, such as PDAs (Personal Digital Assistants) with limited technical resources. At the information booth, a user can download the display application for her PDA over an infrared connection, she can chose, where she wants to be guided, or what kind of additional information she is interested in. The presentation has to be tailored to the limited display capacities of mobile devices by generating route descriptions in a simple sketch-like manner. After leaving the booth, the PDA filters the information that is relevant for the current user out of a data stream, which infrared transmitters spread throughout the building constantly. The underlying protocol was developed specifically to guarantee that simple or abstract information becomes available immediately, while more details can be accumulated when the user stays within the range of one transmitter for a longer period of time. Therefore, a passenger in a hurry might only see an arrow pointing in the direction of her destination, while someone pausing at a place will soon dispose of a detailed environment map containing additional information about, e.g., nearby shops or restrooms.

In order to generate such presentations, the system has at least to go through the following steps: the selection of the information to present, the determination of a presentation structure, and the graphical realisation of the actual presentation. In addition, the information to be presented should be tailored to the particular strengths of each presentation medium, but should also be selected according to the current environment/context. Our systems generates several different presentations for a single way description using the same data, i.e. a 3D-model of the domain enriched with additional structured information (e.g., about landmarks and a route graph).

In Section 2, we give a short introduction to our notion of resources and resource adaptivity. Section 3 relates our work to the models and concepts of human wayfinding research and human spatial cognition. In Section 4, we present the several visualisation techniques for route description. Section 5 showcases our ideas about how to modify computed trajectories in order to visualise the core meaning of path relations.

2. Resources

The graphics, which are used to communicate content between a sender and a receiver (in this case the machine and the user), should be adapted to a given situation as much as possible. Whenever graphics are presented to a human viewer using a certain medium, two different types of resources play an important role: on one hand, all the technical resources of the selected medium, and on the other hand, the available cognitive resources of the current user.

2.1 Technical resource restrictions

Technical resource restrictions include all types of limitations to the presentation platform. Here, two main types can be identified:

- restrictions of the output medium, and
- restrictions of the generation process.

The output medium is the visual interface to the viewer. Typical output media are printed paper, and computer displays, which also include 3D-displays such as stereo glasses. All these media are at least restricted by the inner and outer scale (Hake, 1982). Those terms stem from cartography, and describe the maximum size of the displayed graphics (outer scale) and its resolution (inner scale). They determine the amount of detail that can be displayed. For example, it is not possible to infinitely reduce the size of an image without loosing important details. If the outer scale of the display is limited, it might be necessary to enlarge some smaller details that are important, and to omit others, which are less relevant for the task at hand. The availability of colour is another important limitation: Colours often encode important information about the depicted objects. Colour can also help to focus on important objects or. If colour is not available, the system has to convey this kind of information by other means, or has to omit it completely. Additionally, the graphics generation process itself depends on resources such as CPU-time and memory. These are often critical in real-time applications, e.g., in the scenario mentioned in the beginning, where a complete way description has to be rendered and displayed for passengers hurrying to catch a plane.

2.1 Cognitive resource restrictions

One of the most important cognitive resources of a viewer is her working memory. In our work, we simplify the limitations that are connected to the working memory to three classes of parameters: time restrictions, domain knowledge, and familiarity with the presentation type. Time restrictions can be divided into two different types: The viewing time is the time the viewer is given to look at the graphical presentation. In contrast to this, the decoding time describes the time the viewer needs to decode the presentation and understand it's meaning. Both times may be very limited, especially when the viewer is heavily stressed. Complicated presentations that must be decoded under time pressure often lead to vicious circles, where the sense of not understanding results in stress, which in turn reduces the ability to decode the presentation and so on. The domain knowledge of the viewer also influences the decoding time in two ways: On one hand, she might be familiar or unfamiliar with the type of the presented graphics, e.g., whenever certain coding conventions (e.g., symbols or icons) are used. On the other hand information might be familiar or unfamiliar, e.g., parts of the way a pedestrian has to walk.

2.3 Types of resource adaptivity

Graphical presentations and a system generating them can respond to limited resources in various ways. For our work, we differentiate the terms resource-adaptive, resource-adapting and resource-adapted. A resource-adapted process will make optimal use of a given medium under given circumstances. In order for a process to be called resource-adapting, it will have to react to changing resource limitations, e.g., yielding lower quality results. A fully resource-adaptive process will react to upcoming resource limitations during run-time, and it might even come up with a new strategy in order to still yield satisfactory results under the new restrictions. For a more thorough discussion of these terms see Wahlster & Tack (1997).

3. Spatial representations and route descriptions

Route descriptions can be given by different presentation means, e.g. by drawing a sketch of the route or by describing the route verbally. They should help the addressee in constructing a cognitive map of the environment, and enable her to reach her goal. Different forms of spatial representations can be identified in complex surroundings. In the area of spatial navigation tasks, a distinction is made between landmark, route, and survey knowledge of an environment. Landmarks are unique objects at fixed locations, routes correspond to fixed sequences of locations (as they are experienced while following a route). According to Sorrows, and Hirtle, (1999) landmarks are elements of the environment, which are external to the observer, and serve to define the location of other objects or locations. They are memorable cues selected along a path, and they enable the encoding of spatial relations between objects and paths, leading to the development of a cognitive map of the environment. Landmarks are generally used in navigation tasks to identify decision or destination points, and to convey route progress. They influence expectations, provide orientation cues for homing vectors, and suggest regional differentiating features. Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa (1998) stated that route knowledge differs from survey knowledge in three main aspects: (a) route knowledge is accessed sequentially using an ordered list of different locations, (b) the number of path emanating from each location is small, and (c) an egocentric reference system is used to decide where to go from a given location. Survey knowledge abstracts from specific sequences and integrates knowledge from different experiences into a single model. This form of representation allows route independent access to different locations, enables the inference of spatial relations between arbitrary pairs of objects, and is organised in a global allocentric coordinate system.

Static maps are a common tool for the depiction of routes. They show a path through the environment from one location to another, and can be used effectively to visualise and depict route directions. Usually maps show a route as a sequence of turning points connected by lines. In addition to visualisations from an egocentric view, maps convey survey knowledge about the environment, e.g., regions or the structure of the environment from a bird's eye view using an allocentric frame of reference.

Verbal route descriptions describe a motion path in an environment mostly from an egocentric frame of reference. Normally, they encode the path to follow including landmarks, and they mention spatial relations between objects in the current environment. The addressee undertakes a mental journey (see also Schmauks, 1998; Maass & Schmauks, 1998), during which elements in the environment are localised in relation to her current position or to each other from an egocentric point of view. This view, sometimes called route perspective (cf. Tversky, 1993) or field perspective (cf. Schweizer, Herrmann, Janzen, & Katz, 1997), is helpful to convey knowledge about path segments and landmarks (route knowledge). For the transfer of survey knowledge, often a different point has to be chosen, e.g., in order to provide information about regions or the structure of the environment e.g., or to help the addressee to take a short cut. Elements of the scene are referred to in an allocentric frame of reference corresponding to a survey perspective of the environment (see also Tversky & Lee, 1998; Tversky & Lee, 1999; Herrmann, Schweizer, Janzen, & Katz, 1997). Furthermore, human beings have no problem to switch between those frames of reference and understand descriptions like: "Go east through the hallway, until you reach the book shop; turn left there."

In our case, we would like to visualise the virtual journey, i.e. a course of motion in a given environment. The visualisation therefore focuses on this course of motion from a mainly egocentric frame of reference. Elements of the environment are localised relative to the agent's position or relative to each other. For the transfer of survey knowledge, information about regions or the structure of the environment has to be included. In this case, we have to choose a suitable viewpoint to look at the scene, for example, a bird's eye view on a visualised map. In addition, a certain amount of redundant information is generally useful in route directions, e.g. to reassure the addressee that she is still on the right way (cf. Hirtle, 2000). Following Tversky, and Lee (1998), we divide a motion path into segments. Each segment consists at least of four parts belonging to different categories: starting point, reorientation(orientation), path/progression, and ending point. Since the paths we would like to visualise are continuous, the ending point of one segment can serve as the starting point for the next one. A route can be divided into segments, whereupon the segment borders are induced by changes of direction in the route. In the presentation such a change in direction must be clearly communicated.

In our computational model a segment represents a partial view of the environment by integrating different kinds of knowledge. We represent knowledge about paths in a graph. Nodes of the graph correspond to turns or intersections in the real world. Edges correspond to paths between two points in the real world. In order to clearly describe or visualise path segments, we have to integrate knowledge about different types of landmarks from an annotated 3D model. Landmarks at decision points are necessary to communicate a reorientation and/or path progression, and should be located near turning points along the path. Depending on the next segment in the sequence we focus on objects in the direction of the path ahead of us. This is in accordance to experiments described in Maass (1996), where test persons had problems to generate appropriate descriptions of a turn-left action when they were forced to refer to an object on the right hand side of the intersection. Road landmarks are located along the path, but not at a specific decision point. Pointing out potentially wrong choices at road landmarks can be used to assure that the addressee stays on the right way. Finally, we also integrate the addressee's own current position, which allows us to compute spatial relations between her and objects in the environment, and to describe locations from her egocentric point of view.

The generation process for graphical way descriptions starts with a search for an appropriate way for the current user of the system. The search is performed by an adaptive search algorithm, which tries to find an optimal way for the current user. It uses a user-model about known and preferred routes in the environment and different strategies to optimise the route, e.g., it minimises the amount of turning points, thereby reducing the number of possibilities to take wrong turns. The resulting path can be divided into segments in the aforementioned way. After a presentation planning process, which is beyond the scope of the work presented here, we are able to visualise the route using different graphical techniques presented in the following section.

4 Graphical techniques for the visualisation of route descriptions

This section describes several techniques that can be used to generate visualisations of a path or trajectory, taking into account limited resources of the system and the viewer (see section 2). At this point, the relevant objects of the scene are already determined as explained in section 3, and the graphical realisation can begin.

We will discuss different graphical techniques customised for different cognitive loads of the viewer and/or different time restrictions. We use these techniques to generate graphical route descriptions for the aforementioned information booth that can supply the navigator with all kinds of information she might require.

4.1 Sketch rendering

When time is constrained and/or the addressee is heavily stressed, we consider black and white sketches as a good way to reduce the amount of available information to a minimum: only the most relevant details are presented, focusing the viewer's attention on the important parts of the route, i.e. the trajectory the addressee is supposed to follow. In addition, sketches of the environment have the advantage that they can convey overview knowledge of the environment, e.g., the spatial configuration of rooms in a building, as mentioned in section 3. Generating a sketch version of the path to follow is an easy task, since it is already approximated by a number of points in our representation of the environment. The points can be connected with lines in different line styles, e.g., a dotted line with an arrowhead depicting the direction (see Figure 2).

Figure 2 about here

The visualisation of the environment (consisting of several reference objects that help to localise points on the trajectory) in 3D-space is more complicated. The detailed 3D-objects that may serve as reference objects have to be displayed in a simple but comprehensible way. Here, we rely on non-photorealistic rendering techniques similar to the ones already introduced in Strothotte (1998); Schlechtweg & Strothotte (1996). Instead of displaying all edges of a 3D-model (the typical wire-frame model) these techniques try to find the edges that are visually more important than others, and only those will be used for the visualisation. Such edges can be determined by a certain threshold angle or by edges that divide a visible from an invisible polygon under consideration of the current point of view. Since our system knows about the goals of the viewer, it can additionally include or exclude particular details. Let's assume that a navigating passenger in an airport wants to buy a book along the walk to her gate but time is very limited. In this situation, a sketch is better then a lengthy animation showing the direct way from the current location to the gate. Nevertheless, bookshops on her way should be included into the realisation, whereas all other shops can be oppressed. In order to get a real sketch resembling a floor plan from the 3D-model, a parallel projection orthogonal to the trajectory plane is chosen, in which the 3D-model is clipped in order to make the doors appear open (see Figure 3).

Figure 3 about here

In addition different line styles (dashing, line thickness, grey value) can be used to emphasise or de-emphasise certain details of the graphics. The sketches are generated at a 3D-Graphics workstation to build interactive incremental presentations, which are broadcasted over infrared transmitters used by our indoor navigation system (cf. Wahlster, Baus, Krüger, & Kray, 2001).

Simple sketches yield static graphical presentations, but animated elements can be added in a simple way. The guided person, for example, can be represented by a red dot in the plan that moves along the trajectory from the current location to the target point. In order to make the presentation more human-like the dot is not strictly moved along the trajectory but wanders a little bit off to the left or right. Especially when taking 90 degree turns, the movement is smoothed into an arc, using spline functions, instead of abruptly changing direction.

4.2 Animation styles

When time is not tightly limited, more elaborate visualisations of the path can be generated and presented to the addressee. This includes a walkthrough through the surrounding environment at the highest level of detail. Several empirical studies suggest that a path presented from an egocentric perspective can be memorised more easily than a simple map view (e.g. Schweizer, Herrmann, Janzen, & Katz, 1997). One reason for this is that the ego perspective is the natural way to see the world. Therefore, this technique should considerably improve the construction of a cognitive map of the environment, as it is closely related to our daily perceptual experience in navigation tasks, whereas a route can be seen as discrete sequence of objects or events - for example a rendered sequence of pictures from an ego perspective at decision points on a path (see Figure 4) -, it can also be continuous, e.g., in case of an animation along a trajectory in ego-perspective.

Figure 4 about here

More realistic rendering techniques (textures, lights, shadows) and more geometric details support a better immersion of the addressee into the scene. Since we know the changing position and viewing direction of the addressee in the scene, we can establish an egocentric frame of reference, and we are able to use directional spatial relations like “in front of”, “behind”, “right” and “left” to describe situations.

Figure 5 about here

Figure 5 shows the egocentric frame of reference we rely on in our computational model. The reference system differentiates between eight primary directions. In order to determine the corresponding spatial relations we use an efficient ray casting procedure. From the actual position in the scene we cast rays into the environment. For each of the primary directions we specify a range the ray has to cover, and this range defines the applicability area for the spatial relations. The definition of these applicability areas is based on experiments on projective spatial relations described in Zimmer, Speiser, & Baus (2001). For each ray we determine if the ray hits an object oft the environment. If that is the case, we can compute the intersection point of the ray with the object. The intersection test also yields distance and direction from the actual position to the object in question. The corresponding spatial relation can then be used to describe the object′s location verbally. Furthermore, we can attract the addressee′s attention to important objects along the route by highlighting an object, by annotating it, or by drawing an arrow pointing to it. Presenting landmarks at decision points in the visualisation supports the formation of decision sequences and facilitates the generation of picture sequences of the route to remember. The working hypothesis is that this leads to an enhanced performance in the way finding task later on in the real world. We developed different animation styles for the presentation of routes: We can visualise a route entirely from an ego-perspective point of view, moving the camera along the trajectory from a start location to a destination. Similarly to the moving dot in the animated sketch described above, the movements should be smoothed at sharp turns to obtain a more human-like behaviour. These movements can be computed directly from the trajectory. Smoothing is done with spline interpolation between trajectory points. Furthermore, we use ″head movements″, which are actually slight camera rotations to the left or right, to focus the viewers attention to important details (e.g., landmarks) along the route. Such camera turns can be performed without interrupting the walk along the path resulting in a nested movement of the field of view. This is similar to the effect a person will experience in the real world when looking besides her while walking straight on (see also Chopra-Khullar & Badler, 1999). In such a situation, problems may occur when the viewing direction differs too long from the walking direction. Therefore, we have the ability to slow down the overall walking speed during head movements to avoid irritations of the viewer.

The next step is the introduction of a 3D presentation agent (see also Noma & Badler, 1997; Johnson & Rickel, 1998) that gives a guided tour along the path, visualised from a camera positioned slightly behind and above the virtual presenter facing in the direction of movement (see Figure 6). Gestures performed by the virtual presenter can underline important details along the way. The movements of the presenter can also be used to highlight spatial configurations. Instead of walking along the direct connection between two points the persona can emphasise a landmark by approaching it, trading a longer way for the chance to convey more information. Following Towns, Voerman, Callaway, & Lester (1998) a key problem posed by life-like agents that act in virtual worlds is *deictic believability*. They should refer to objects in the environment in the same way as humans do: through combinations of speech, locomotion, and gestures. Therefore, the virtual presenter should be able to move through their environment, point to objects and refer to them appropriately. Deictic believability requires considering the physical properties of the presenters' world. It must exploit its knowledge about the positions of objects in the world, its relative location with respect to these objects in order to create deictic gestures, motions and utterances that are natural and unambiguous. To reach these goals the virtual presenter has to handle spatial deixis effectively, and it must be able to establish an egocentric frame of reference as described above. Distance and direction of surrounding objects, which are determined by the reference system, can be used to control the virtual presenters′ movements and pointing gestures.

Figure 6 about here

In addition to the ability to perform gestures, the virtual presenter itself has to meet several requirements. According to its functional roles in the presentation, it must be ``familiar'' with a range of presentation gestures and rhetorical body postures (e.g. standing upright) and should adopt a reasonable and lively behaviour without being distracting or obtrusive. Here, we propose a high level declarative specification of the presenter's top level behaviours. These top level behaviours automatically generate the virtual presenter's animation (cf. Baus, Butz, & Krüger, 2000). In order to achieve natural movements the virtual presenter's navigational behaviour generates a spline that interpolates between points on the path from the virtual presenter's current location in the environment through a list of successive control points to the target destination. The navigational behaviour consists of different hierarchically structured behaviours, for example, behaviours for leg movements. The virtual presenter has the ability to perform different gestures to emphasise certain aspects of the path to follow. The point-at behaviour is a composition of different other behaviours, e.g., move the presenter's arm, slightly rotate the body. The look-at behaviour consists of a rotational movement of the presenter's head, and eventually, a body rotation. These two behaviours enable the presenter to point and/or glance at an object and to draw the addressee′s attention to the object in question. It should be stated that all the actions constituting the different behaviours can be done in parallel and at different speeds.

Knowing minimum and maximum speeds for the different behaviours/actions and the locations of objects in the environment from the presenter's point of view allows us to specify only an abstract presentation plan. The virtual presenter will perform the task alone without system intervention.

If time is critical we can omit the visualisation of the animated virtual presenter and replace and switch to the aforementioned visualisations from an ego-perspective, or we can replace the virtual presenter with a symbolic representation, e.g. a red dot moving on the ground along the trajectory. In such a situation, we must change the camera position to show the virtual presenter′s moving representation. Nevertheless, we have the opportunity to choose between different camera position, e.g. for visualising an animation from a birds-eye perspective, where the camera moves along a trajectory right above the moving presenter facing downward to show the presenters′ iconic representation. In this case, since we visualise the assumed addressee′s position in the current environment we still can use the egocentric reference system to compute directional spatial relations to coordinate the presentation, e.g. drawing an arrow pointing to the object in question at the right time, instead of a pointing/looking gesture of the virtual presenter (see Figure 7).

Figure 7 about here

In addition to the varying animation styles, we developed different methods to perform changes between the camera styles: We can switch directly between camera styles resulting in a cut between two scenes known from cinematography. Alternatively, we can animate the transition between styles, which results in a seamless camera movement.

In this section, we introduced different techniques to convey route description by graphical means. Although, there are major differences between those techniques, they have one thing in common, which is that they serve to visualise a trajectory through the environment. In static sketches we simply draw the path obtained from our search algorithm, in animated sketches we move a representation of the addressee along the trajectory. When we present 3D animations through the environment things are more complicated as we have to differentiate between two cases: In a simple animation from an ego-perspective point of view, the current position of the camera and the current position of the addressee in the environment are coincident. When we show an animation of a virtual presenter along a path from a different point of view, e.g. birds-eye view, the camera position and the position of the virtual presenter are more or less independent from each other, although the camera should always be adjusted to visualise the presenter or its representation moving along a trajectory. In the next section, we will present our ideas for the modification of trajectories in order to better visualise the core meaning of path relations in the context of route descriptions.

5 Visualisation of path relations

The graphical techniques presented so far enable us to convey configurational and route knowledge from different points of view, and we can compute and visualise directional relations between objects in the scene. The next step is to visualise path relations adequately, since path prepositions/path relations such as "along", "past" or "across" are often used in path descriptions or navigational instructions. But until now, only limited effort has been put into the investigation of their properties and into modelling them. Most research emphasises the importance of turns, landmarks and spatial utterances describing spatial relations such as distance-dependent (e.g. "close to"), directional (e.g. "left of") and topological relations (e.g. "in "). But spatial utterances describing path relations convey a lot of information using a single relation. For example, describing a trajectory following a river can be achieved by the simple use of "along" instead of a lengthy sequence of instructions. The relevant point here is that path relations relate to the shape of an reference object, whereas distance-dependent and directional relations, like the ones used to establish the virtual presenters egocentric frame of reference do not.

In order to compute/visualise path relations, we have to specify the concepts we have to model to describe trajectories in relation to the shape of a reference object. Starting from the assumption, that the reference object introduces a division of the surrounding space into different regions (see Figure 8). For the course of a trajectory it is possible to cross region borders or to cross complete regions. They could approach to the reference object or depart from the it.

Figure 8 about here

Furthermore, trajectories can be parallel, partially parallel, and not parallel to the shape of the reference object. We conducted a series of experiments reported by (cf. Zimmer, Speiser, Baus, & Krüger, 2001; this volume), where we try to find out if it is possible to specify spatial features between a trajectory and a reference object that are relevant for the communication of path relations in graphics, similar to those for projective relations. The first experiment was designed as a paper and pencil test, where subjects were required to draw prototypical paths in layouts showing a reference object with different shapes for spatial utterances like: "Gehe am Gebäude entlang" (Walk along the building) or "Gehe am Gebäude vorbei" (Walk past the building).

Figure 9 about here

Figure 9 shows some of the results, where we digitally overlaid the pictures produced by the subjects, which were instructed to visualise the spatial utterances "entlang " (along) and "vorbei" (past). The trajectories drawn to visualise the spatial utterance "entang" (in the upper part of Figure 9) follow the shape of the reference object, while those for "vorbei" (in the lower part of Figure 9) mostly take the shortest path from the starting point to the destination point. For reference objects with different shapes we observed comparable results, the trajectories produced to depict the locative expression "entlang" followed the shape of the reference object exactly and were close to the reference object. The use of "vorbei" as a locative expression for describing the trajectory resulted in drawing a more ore less direct line between the start- and end-point of the trajectory, ignoring the reference object's shape. From the data collected, we were able to conclude, that for the usage of the locative expression "entlang" two critical spatial features constraining the trajectory's shape must be fulfilled: The trajectory must be parallel to the reference object within a certain region and the trajectory must be close to the reference object. The locative expression "vorbei" turned out to have a more fuzzy meaning, as it does not, e.g., require the shape of the trajectory to relate to the shape of the reference object (cf. Zimmer, Speiser, Baus, & Krüger, 2001) in any way. Inspired by these results and by the visual impression from the sampled pictures, we tried to develop a method for visualising trajectories, that encodes the core meaning of the used locative expressions adequately by conforming to the results form our first experiment. The key idea is to let the reference objects attract the motion path in a similar way as people are cutting corners in reality. The trajectories should, for example, bend smoothly around the reference objects.

In our first computational model the trajectories are modified depending on the object's shape to approximate the trajectories to the prototypical trajectories obtained from the experiment. We developed a rapid prototype implementation to visualise the trajectories for the locative expressions ″entlang″ and ″vorbei″ in a two dimensional layout. We were using a potential field, which attracts the trajectories and modifies them according to the spatial utterance we want to visualise. In our approach we used a black and white bitmap, where we assigned the white area to a trajectory′s start point and the black area to a trajectory′s end point. In the next step we inverted the reference object′s bitmap recolouring the formerly black reference objects white. These two bitmaps have been digitally overlaid and processed using a gaussian image filter. Through the use of this image processing method, we were able to compute a gradient field, in fact a distribution of grey values in the resulting image. Using the obtained gradient field of grey values, we can compute the shape of the trajectory visualising the spatial utterance by a simplified form of physical simulation. The simulation consists of moving a sphere through the gradient field. We assign an initial speed to the sphere and define a mapping from grey values in the gradient field to gravity values, with increasing gravity values from white to black. Depending on its gravity value, a pixel in the image attracts the moving sphere and therefore influences the sphere′s path of motion. With an additional parameter we determine how often the computations described above should be performed, e.g., for every pixel or for every 10th pixel. Through the use of this computational model we were able to visualise trajectories which were comparable to trajectories drawn in the experiment for certain parameter values. However, when we tested different parameter values, we found some problematic cases.

Figure 10 about here

In the left part of Figure 10, the sphere accelerates very fast, enters the area of the reference object, bounces back and moves directly into the goal direction. The right part of Figure 9, the sphere was caught in a local minimum during the simulation and did not reach the goal at all. Despite these problems of parameter control, we found out that it is possible to compute trajectories that visualise the path to follow in a two dimensional layout according to the intended meaning of the spatial utterances ″entlang″ and ″vorbei″. But the crucial point in this computational model is that we can not predict the result we will obtain from the simulation and especially in cases where the sphere did not reach the goal in the simulation we would not obtain a suitable visualisation. Furthermore, we found out that image processing methods are unpractical to combine with our proposed model for the generation of graphical route descriptions. Starting from the data of our 3D model, we would have to render an image from a suitable birds eye view of the scene. Afterwards, we would need to compute the result of the physical simulation, and then transform the resulting trajectory into a spline representation suitable for a camera animation through the scene. For these reasons, we discarded our first implementation. But based on the results of the experiment, which suggest that parallelism an closeness are important concepts for modelling and visualising path relations, we are now investigating a model, which uses the trajectory obtained from our search algorithm as a basis for the modified trajectory. This will allow us to ensure that we will obtain a visualisation of a route as long as there is a way from a start destination to goal destination. The model will also take into account the results from our speech production experiments. In these experiments we systematically varied the concepts of parallelism and closeness to investigate the critical features for the selection of certain path relations. The experimental setting and results are described in detail in Kray, Baus, Zimmer, Speiser, & Krüger (2001) and Zimmer, Speiser, Baus, & Krüger (2001). Two main results were drawn: On the one hand, it became clear that parallelism between a trajectory and the outline of a reference object is a necessary precondition for the applicability of “along”. In the path production experiment, subjects took great detours to assure that the drawn trajectory was at least partially parallel to the reference object. On the other hand the effect of distance to the reference object was not entirely clear. Closeness yielded faster response times in case of parallel trajectories, but there were also trials where closeness induced a higher percentage of subjects choosing “along” in case of partially parallel trajectories. So, the conclusion can be drawn that closeness is a secondary criterion that is called upon in cases where the degree of parallelism is not high enough to justify the selection of “along”. However, there are some problematic cases, e.g., where trajectories are very far away from the reference object but still parallel. Currently, there are several new experiments underway, where we investigate how dynamic trajectories influence the selection of spatial utterances. In these experiments we use a point moving over a sequence of predefined points, so that the trajectory′s shape emerges from the movement of the point, comparable to the visualisations described in section 4. We vary the trajectories start and end point in relation to the reference object, the shape of the reference object and the speed of the moving sphere. From these experiments currently under evaluation, we hope to find out the relevant factors that will enable us to develop a computational method for the visualisation of path relations. The key idea is that we try to define a mapping from points on the edges of a reference object onto the shape of the trajectory obtained from our search algorithm. In accordance with the current presentation speed and the addressees intended actions in the environment we are allowed to move the new points of the trajectory and thereby modify the shape of the trajectory. Depending on these parameters the operator will enable the seamless transformation from a perfect “past” to a perfect “along”. Furthermore, we can use the modified trajectory to determine the motion of the camera directly and the according visualisation adequately adheres the prototypical path as far as possible.

6 Summary

We presented different techniques for the flexible and adaptive generation of graphical presentations in the domain of route descriptions. After a short introduction of scenario and our notion of resource restrictions, we have shown the possibility to generate a wide variety of graphical presentations form a 3D model and knowledge base. The introduced presentations range from simple line sketches with arrows pointing the direction, which are currently used for our location-aware mobile system, to complex 3D-animations that can be used at stationary information booths. Furthermore, we have introduced our first prototype implementation of our potential field method for the visualisation of path relations and the ideas for a more sophisticated computational model for their visualisation.

In the future, we plan to follow several research tracks to evaluate our graphical presentation techniques and to deepen our understanding of spatial utterance describing path relations. On one hand, there are currently several new experiments underway, where we investigate how dynamic trajectories influence the selection of spatial utterances. Additionally, we are planning further experiments on the impact of the presentation medium, especially the on the combination of the introduced graphical presentation techniques. On the other hand, we are in the process of implementing a computational model of path relations, which will be incorporated in our system to visualise these kind of relations adequately.

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Figure Captions:

Figure 1: Different snapshots taken during the visualisation of a route description.

Figure 2: A sketch map derived from 3D data by choosing a birds-eye view and a parallel projection.

Figure 3: Doors are made visible by clipping the 3D-model.

Figure 4: A sequence of pictures taken at decision points along a route.

Figure 5: The egocentric reference system used to compute directional spatial relations.

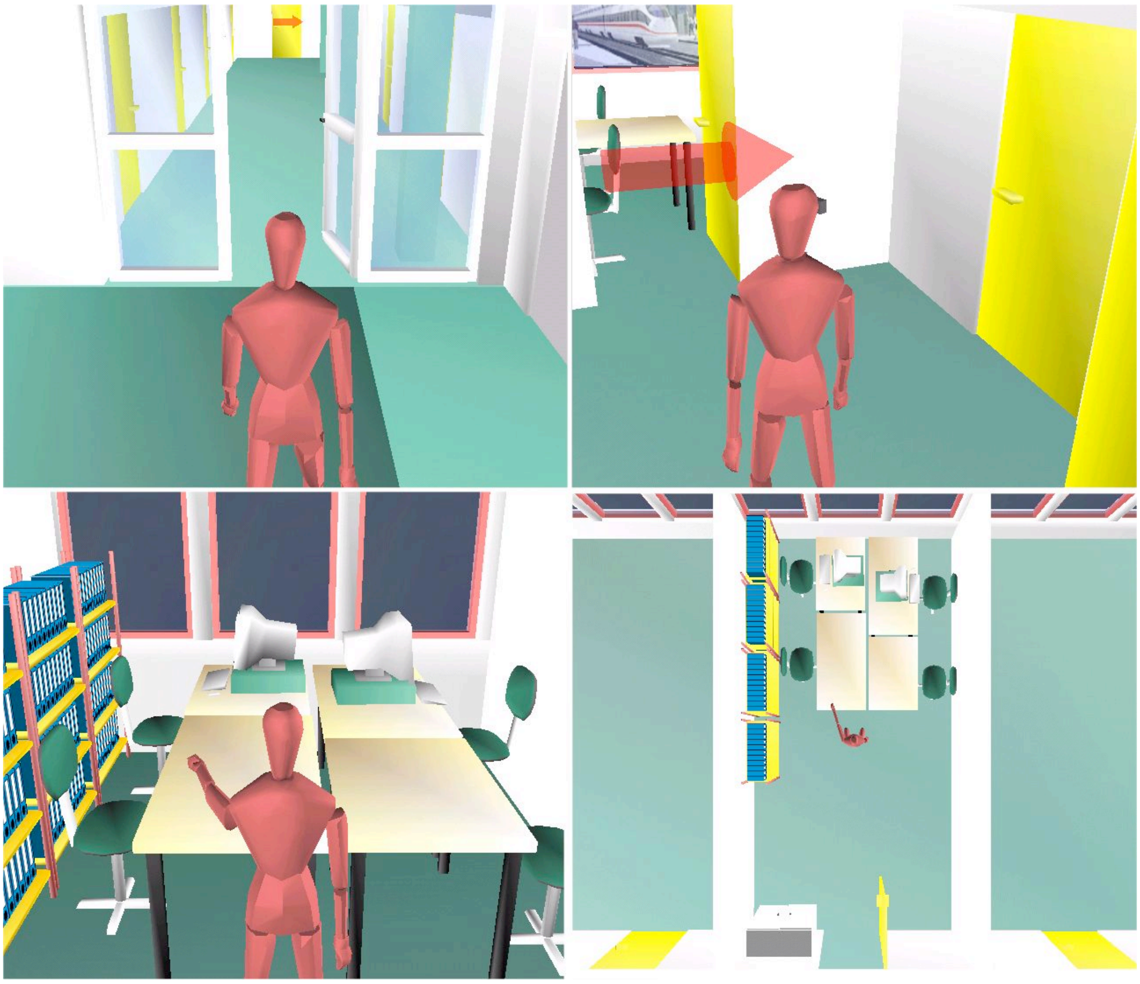
Figure 6: Different virtual presenters performing a point-at / look-at gestures to draw the addressee's attention to a landmark.

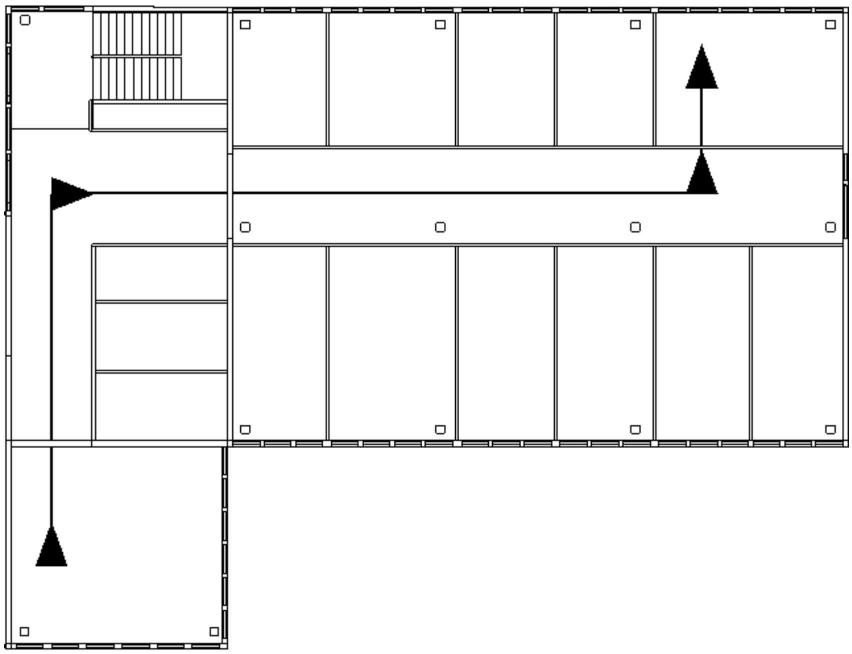
Figure 7: A visualisation from a top down point of view without a virtual presenter, instead using meta-graphics and text to emphasise a landmark.

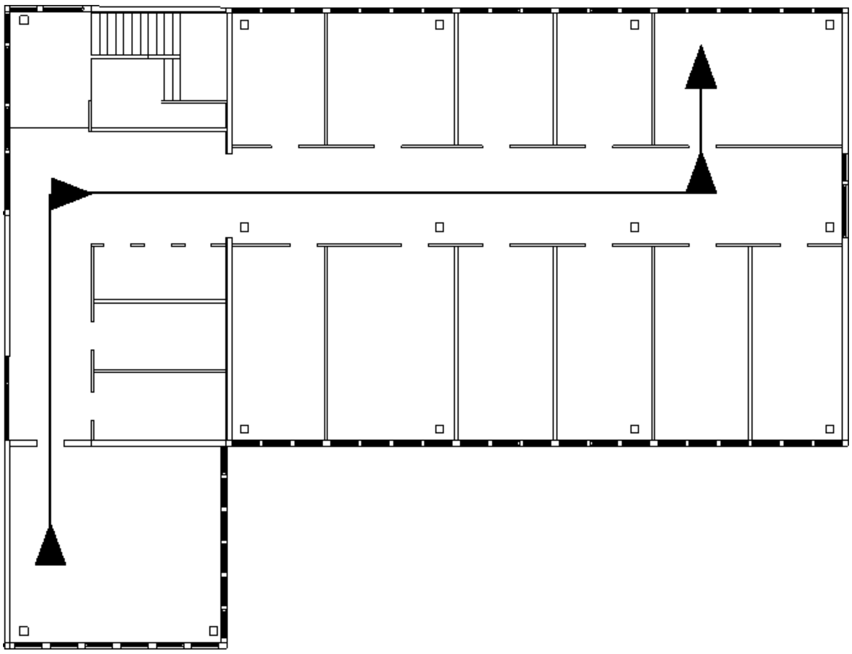
Figure 8: Some examples for the progression of trajectories (t1, t2, t3) and the areas implied by the reference object.

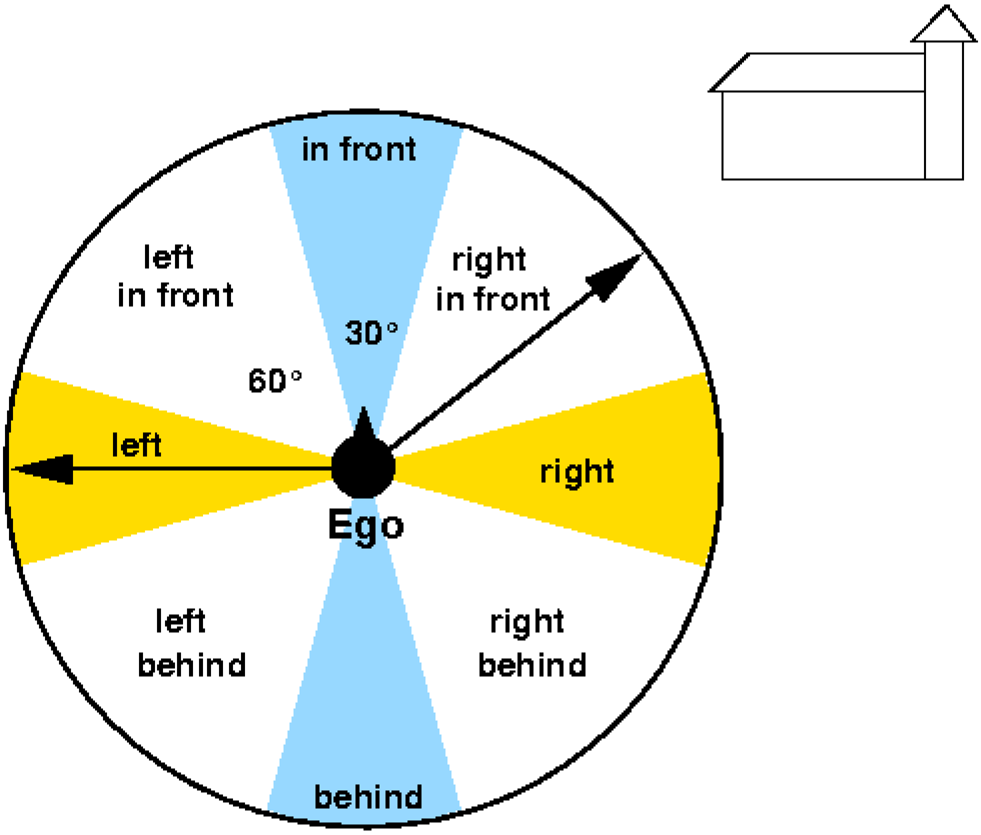
Figure 9: The trajectories drawn for the ´L-shaped′ reference object. The upper part depicts the trajectories for the description "Gehe am Gebäude entlang" (Go along the building); the lower part for the description "Gehe am Gebäude vorbei" (Go past the building).

Figure 10: Results from the implemented potential field method to determine the shape of a trajectory depending on the spatial utterance and the shape of the reference object.





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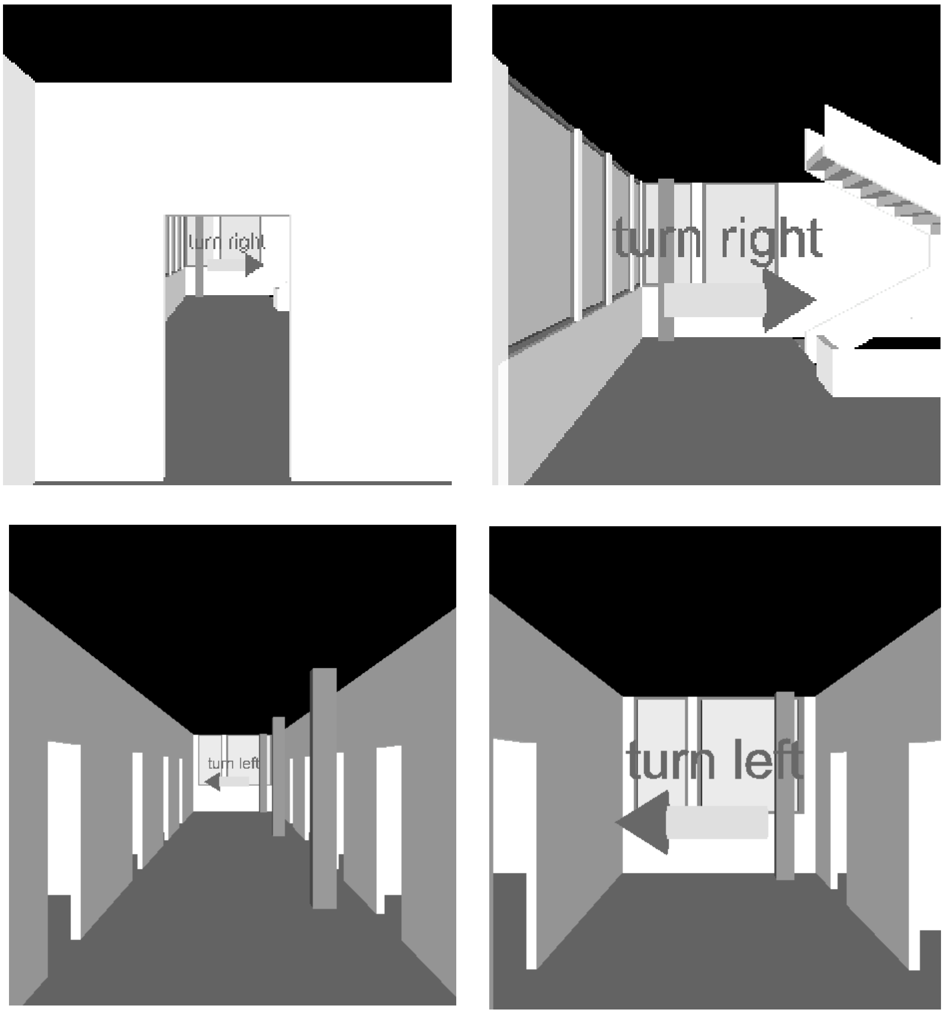
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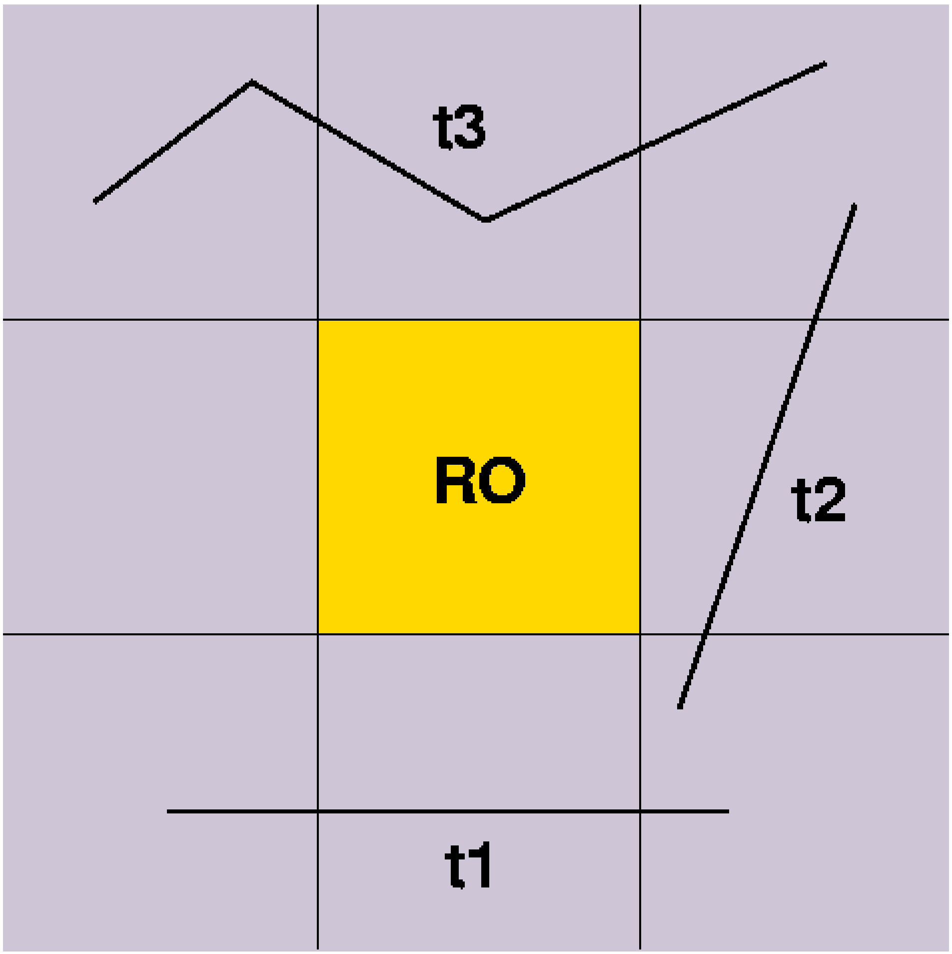
BurgerKing


BurgerKing


Baggage Claim
BurgerKing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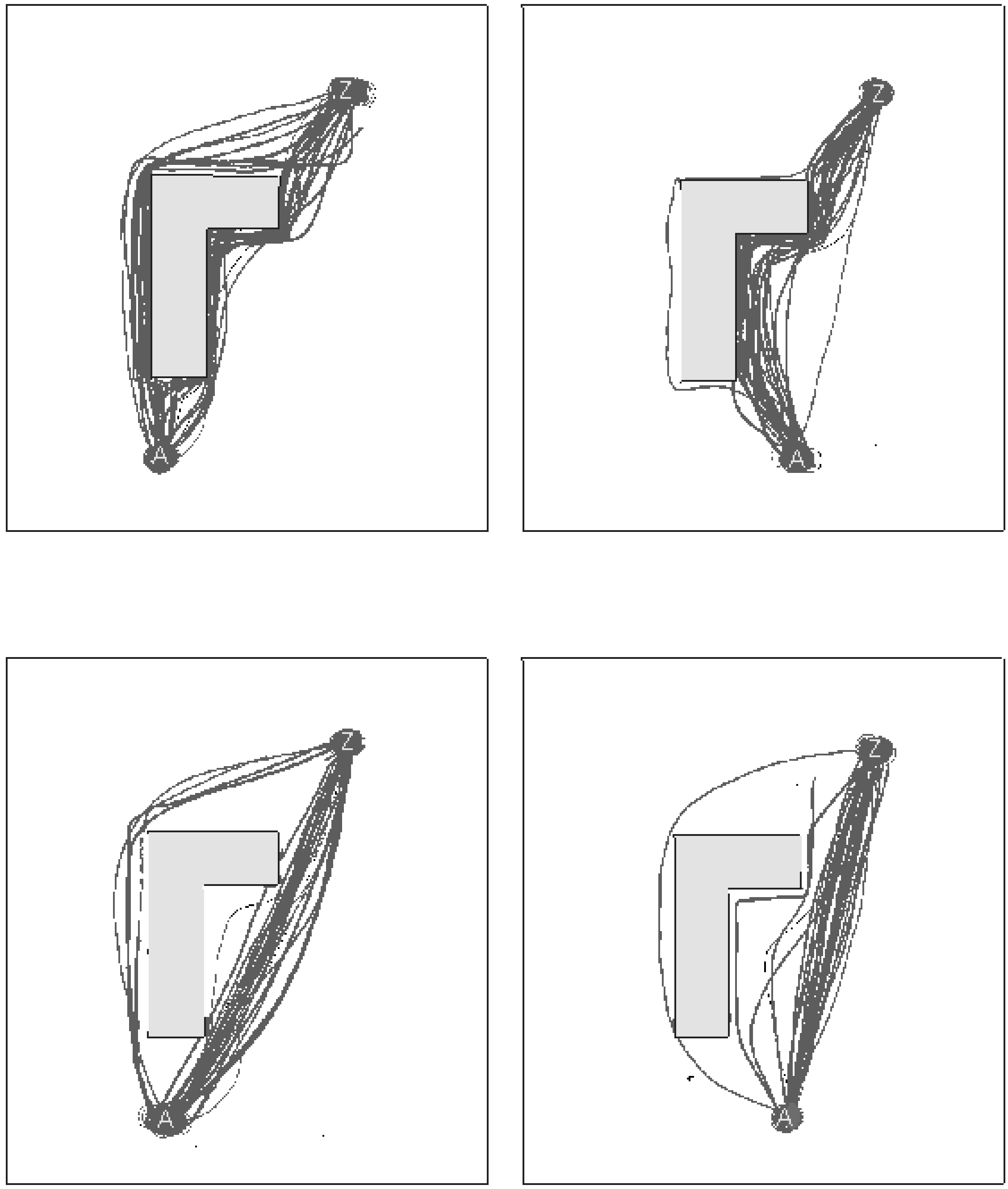
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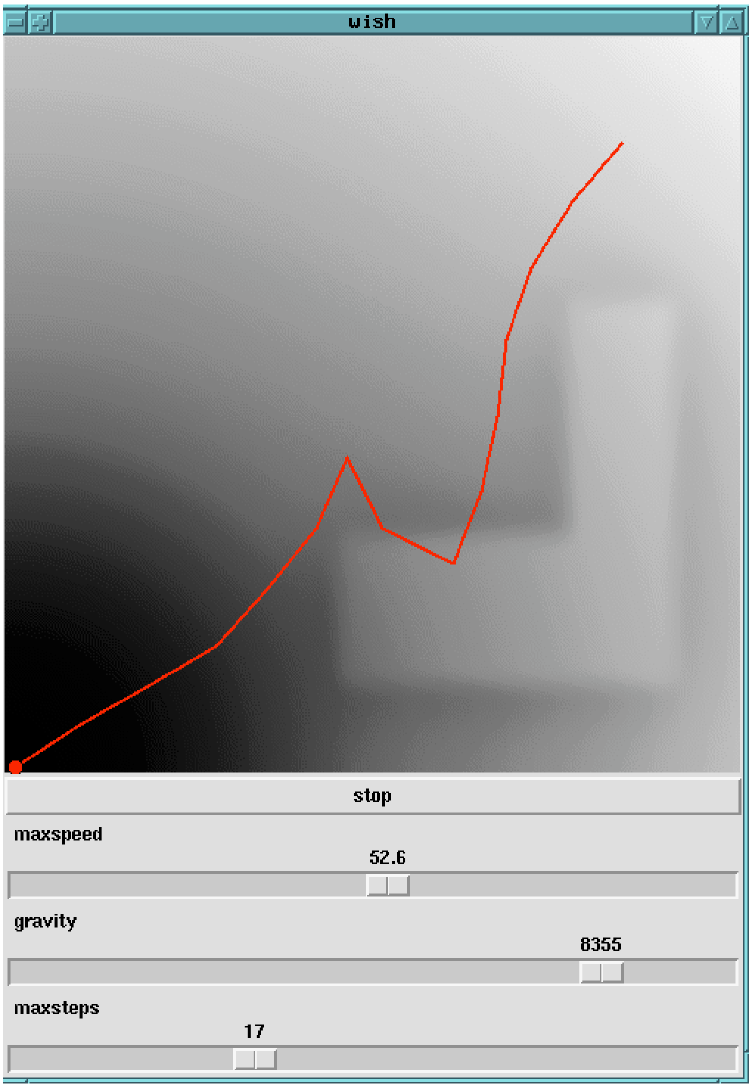
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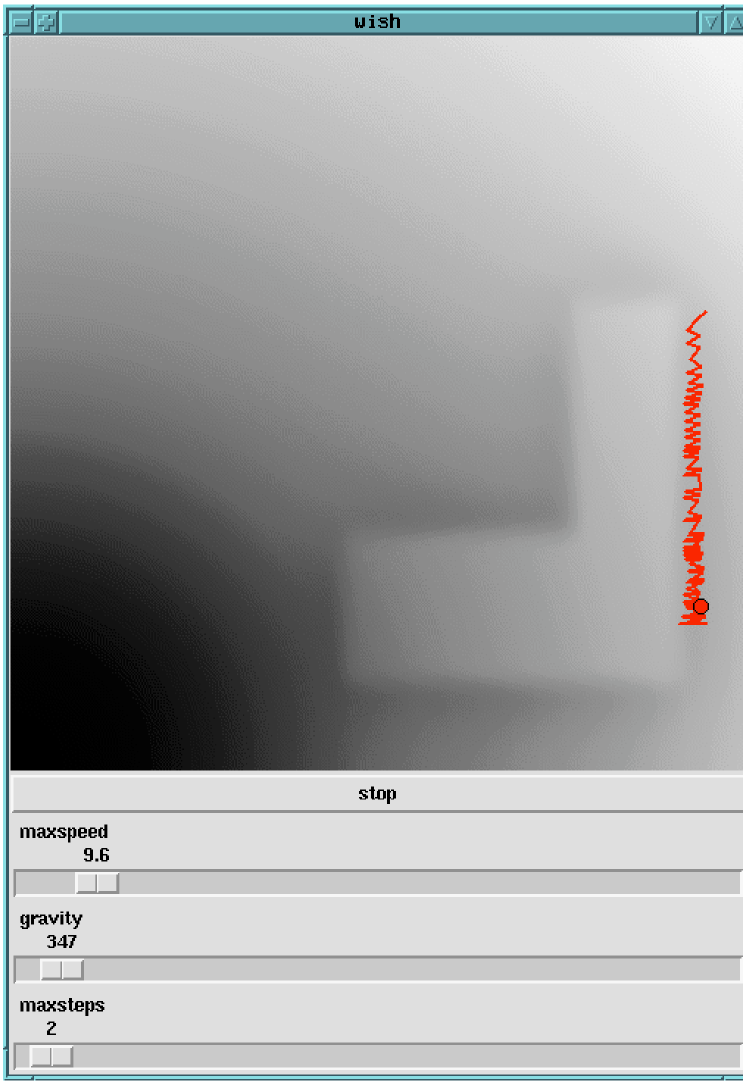
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