

# Psychologically-based Walking in a Cluttered Environment

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## Abstract

*We present a method by which a virtual actor (a computer agent representing a character in an animation) can walk around an environment, automatically stepping over or walking around obstacles in its way. Our algorithms based on theories from visual psychology. The theories used are models of high level visual tasks which can be expressed as simple arithmetic relationships. They can therefore produce realistic behaviour with a low computational overhead.*

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When we walk down a street we are faced with a large number of objects of various sizes: buildings are very large; lamp posts and letter boxes are smaller, and abandoned drinks cans are even smaller. If computers are going to be able to control the motion of virtual actors it is vital that they too are able to walk around this sort of environment in a realistic manner.

At the start of our journey we have a fair idea of where the buildings and other large objects are and can plan a rough path around these. However, this plan will probably not take account of the lamp posts and letter boxes and it certainly will not take into account the drinks cans. We are much more likely to deal with these as we come to them. Planning a path around an environment is a high level cognitive task which has been studied extensively in artificial intelligence and computer animation<sup>6, 4</sup>. Dynamically altering this path due to small obstacles is a much more reactive activity. It takes two forms: we can either step over an object or walk around it. The second has been studied in computer animation as collision avoidance<sup>7</sup> but the first has had little consideration.

We are working on using ideas from psychology of

how humans visually control their behaviour to automatically animate virtual actors in a more realistic manner<sup>2</sup>. This paper presents a system which combines stepping over obstacles and walking around them using a method based on current psychological theories.

## 1. Vision in a Virtual Environment

The most notable aspect of vision in virtual environments is that the computer has complete information about the environment. This is in sharp contrast to computer vision in the real world where the computer normally has only a noisy two dimensional image at its disposal. This complete information removes most of the problems associated with computer vision. However the algorithms controlling virtual actors must produce realistic behaviour. It is important when designing algorithms for visually guided behaviour that realism is maintained while exploiting as far as possible the information available to us so as to perform the task efficiently. The concepts of *invariants* and *affordances* from visual psychology allow us to do this.

## 2. Invariants and Affordances

The psychologist J.J. Gibson introduced these ideas as part of his ecological approach to vision<sup>1</sup>. An *invariant* is a fixed relationship between features of the

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image seen by the person and features of the environment. For example, motion of a small part of the visual field indicates that an object is moving relative to the observer while motion of a larger part suggests that the observer is moving. An *affordance* is a feature of the image of an object which suggests a certain use. For example, an object with a flat top between about 50cm and 1m high can afford sitting on. Invariants and affordances are often closely linked to motion tasks, directly producing the information needed to control the human body.

The reason invariants and affordances are useful for animation is that they can often be expressed very simply as geometric relationships which abstract away the details of how the visual system obtains them. These relationships can be calculated efficiently from the geometry of the environment without simulating any of the lower levels of vision and so give realism while exploiting the availability of information to the computer.

In the next two sections we describe the invariants we have used to simulate walking in a cluttered environment.

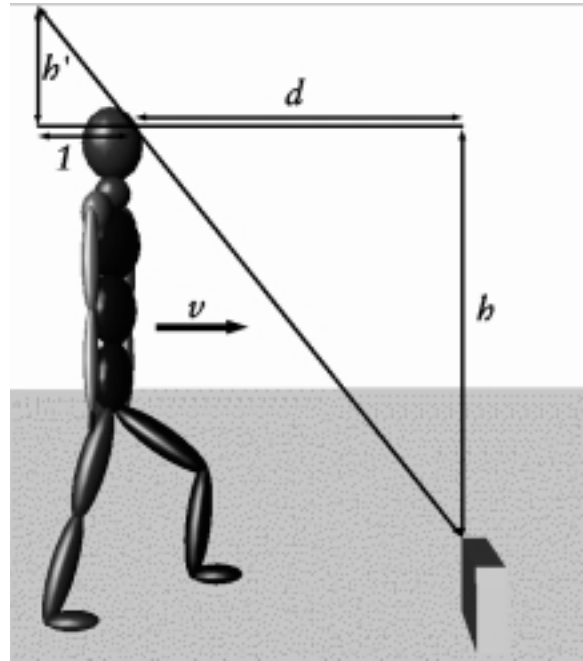
## 2.1. Time To Contact

In his studies of visuo-motor behaviour Lee suggests 'Time-To-Contact' (TTC) as a useful visual cue<sup>3</sup>. In the situation where an observer is moving towards an object with a constant relative velocity  $v$  and the two are at a distance  $d$  from each other it can be predicted that, if their velocities remain constant, they will meet at a time  $t$ , the 'Time-To-Contact':

$$t = \frac{d}{v} \quad (1)$$

Time-To-Contact is a time quantity but it contains some information about both the relative velocity of the observer and the object and their relative distance. It is sufficient information to time an action which must occur as the observer meets the object, for example to catch a ball a fielder needs to know where and when it will cross a two dimensional plane in front of his or her face but does not need to know its velocity or distance at any given instant. It has been shown<sup>3</sup> that many tasks use this sort of time estimation assuming constant velocity, even when the person is accelerating.

As defined in equation 1 the TTC relies on the distance between and relative velocity of two objects, two quantities which are not obviously available to the visual system. If it were necessary to calculate it from these it would not be a useful cue nor one which humans could extract from the environment. Lee, how-



**Figure 1:** An actor moving towards an obstacle with velocity  $v$ .  $d$  is the horizontal distance from the actor's 'eye' to the object and  $h$  is the vertical distance.  $h'$  is the projection of  $h$  onto a plane one unit behind the eye (an approximation to the projection onto the retina).

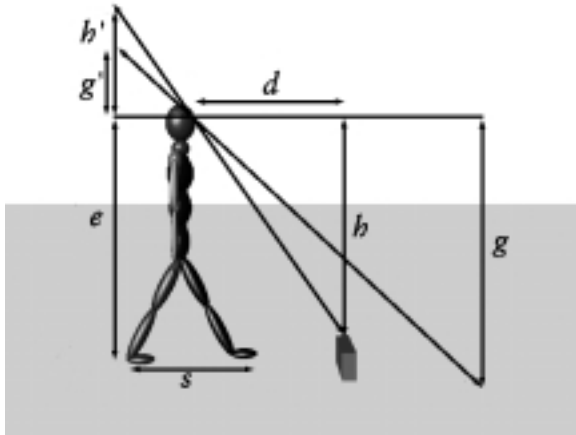
ever, gives an invariant which allows us to know the time to contact. Figure 1 shows an actor moving towards an obstacle with velocity  $v$  and an approximation of the projection of the obstacle onto the retina of the actor. It can be shown that:

$$\frac{d}{v} = \frac{h'}{\frac{dh'}{dt}}$$

The left hand side of this equation is the TTC of the observer with the object and the right hand side is expressed only in terms of the position of the image of the object in the observer's visual field and of its time derivative. Since these are both available as visual quantities the right hand side is a method for obtaining the time-to-contact of an object. This quantity is commonly called the visual  $\tau$  of an object.

## 2.2. Body Scaled Measures

While it is not always possible to have available actual values of environmental variables such as distances and velocities it is often possible to extract measures relating the environment to the observer's body. While it can be difficult to define an aspect of the world in



**Figure 2:** *Body scaled measures.  $e$  is the eye height of the actor,  $s$  is its stride length.  $h$  and  $g$  are the heights of the actor from an object and from a point on the ground and  $h'$  and  $g'$  are their projections*

terms of some unscaled measure it seems natural to do so in terms of a measure which is relative to a body feature, such as the length of a limb. For example, reaching to grasp an object does not require knowledge of the actual distance of the object, just the distance as a proportion of arm length.

Figure 2 shows world distances, distances projected onto the eye and two body parameters against which it is useful to scale: eye height and stride length. The height above ground level  $H$  of an object scaled by eye height can be obtained from the invariant:

$$\frac{H}{e} = 1 - \frac{h}{e} = 1 - \frac{h' \frac{dg'}{dt}}{g' \frac{dh'}{dt}}$$

The distance scaled by stride width can be obtained using visual  $\tau$ :

$$\frac{d}{s} = \frac{\tau}{t_s}$$

where  $t_s$  is the stride time.

### 3. Stepping Over Obstacles

The invariants discussed in the previous section can be applied to the problem of moving in a cluttered environment. The actor must know in which footstep to take action about an obstacle. Measuring the distance to the obstacle in terms of stride length gives this simply. When stepping over obstacles people place their

feet fairly accurately in the step before crossing the obstacle so that in the following step the first foot crosses the obstacle 80% of the way through its stride and the second one 35% of the way<sup>8</sup>. This accurate placement can be achieved by timing the footstep so that it takes a time:

$$t_s = \tau_2 - \tau_1$$

Where  $\tau_2$  is the Time-To-Contact of the end position of the foot and  $\tau_1$  is the TTC of the start position. As the forward velocity is constant the timing of the step can directly control the end position of the foot. This equation is based on a theory of how people control their steps suggested by Warren, Young and Lee in their investigation of running<sup>10</sup>. As the actor walks about the environment it scans the objects in front of it. If the difference between the TTC of any object and the TTC of the actor's foot is within twice the normal step time (i.e. the foot has to step over the object in the step after the current one) it adjusts the timing of the next step so as to place the foot in the correct position ahead of the obstacle.

The height of the foot is controlled as a proportion of leg length so adjusting the height to step over the obstacle just involves knowing the height scaled by eye-height of an object (leg length being a fixed ratio of eye height).

All these invariants can be calculated from their original definitions, which are simply ratios of known values and so efficient to compute.

### 4. Walking Around Obstacles

Not all objects can be stepped over, some are too high. The maximum height a person can step is about 88% of leg length<sup>9</sup>. However, the height of obstacles which can comfortably be stepped over is much lower. Studies have shown that while crossing an obstacle the foot can pass over it by a height of as much as 45cm which is almost half the leg length. Taking this into account and a comfort factor an object is defined as affording stepping over if its height scaled by leg length is less than 40%.

The actor can test any object whose TTC is within than two step times of the current foot (as in the previous section). If its leg length scaled height is less than 0.4 it can be stepped over otherwise the actor has to walk around it.

### 5. Implementation

We have produced an actor which can move around an environment using a simple set of rules to avoid a series

of obstacles of different sizes. It makes decisions as to whether to walk around an object or step over it. The actor adjusts its gait and places its feet in a convincing way. All of the invariants and values needed are computed directly from the geometry which is used to render the scene or from other system values used in the animation, such as the velocity of the actor. These calculations only involve a small number of floating point operations (generally one or two multiplications or divisions) and so the algorithms provide a minimal overhead to the rest of the animation system. The actor is implemented as part of Gepetto, a fully featured actor system developed by Polichroniadis<sup>5</sup>, and runs in real time on a SGI Indigo2 workstation.

## 6. Conclusion

We have implemented a system based on the psychological theories and experimental results of Gibson<sup>1</sup>, Lee<sup>3</sup>, Warren et al<sup>9, 10</sup> and Sparrow et al<sup>8</sup>, which produces realistic animation of an actor moving in a cluttered environment. It shows that invariants and affordances can be used to produce algorithms to control virtual actors. They can exploit the fact that the computer has full knowledge of the environment and so be efficient while maintaining realism.

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