# An Effective Implementation of Agent's Complex Actions by Reusing Primitive Motions

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Abstract: The efficient implementation of various physical actions of an agent to respond to dynamically changing situations is essential for the design of a realistic agent in a cyber world. To achieve a maximum diversity in actions, we develop a mechanism that allows composite actions to be constructed by reusing a set of primitive motions and enables an agent to instantly react to changes in the ambient states. Specifically we model an agent's body in terms of joints, and a primitive or composite motion is performed in a real time. To implement this mechanism, we produce an animation for each basic joint movement and develop a scheme to construct overall motions out of the primitive motions. These motions can be assembled into a plan by which an agent can achieve a goal. In this manner, diverse actions can be implemented without excessive efforts. This approach has conspicuous advantages when constructing a parallel action, e.g., eating while walking, that is, two or more parallel actions can be naturally merged into a parallel action with an arbitration on their priority. We implemented several composite and parallel actions to demonstrate the viability of our approach.

## 1 INTRODUCTION

Apart from the physical realism, the implementation of various physical actions of an agent to respond to dynamically changing situations is essential for the design of a realistic agent in a cyber world (Lee, 2009). However, human actions in a realistic cyber-world reveal such enormous diversity in its motions and actions that it is prohibitively time-consuming to precisely implement all its actions for individual humans. However, the kinds of motions based on Interpolation method or Motion capture, etc. in computer animation are constrained to a small set (Ryu, 2008; Choi, 2006). Further those existing research efforts tend to focus on visual realism, so they are limited in creating diverse actions or reacting to unexpected situations (Parent, 2004). Our modelling scheme for implementing agents' actions in our cyber-world is aimed to maximize their diversity rather than their realism.

To achieve a maximum diversity in actions, our approach defines a set of primitive motions and combines them into composite motions. Some of those motions may be combined into an action to be performed by an agent in order to accomplish its goal. We develop a mechanism that allows complex actions to be constructed by reusing those primitive motions and enables an agent to promptly react to changes in the ambient states. Specifically we model an agent's body in terms of the joints, and devise a scheme to perform primitive or composite motions in a real time. To implement this mechanism, we produce an animation for each basic joint movement and develop a method to construct overall motions out of the primitive motions. Using a small set of primitive motions, we can achieve an efficient implementation of diverse complex actions though sacrificing some visual realism. In this manner, diverse actions that an agent performs to achieve a goal in a situation can be implemented without excessive efforts. This approach has another conspicuous advantage when constructing a parallel action, e.g., eating while walking, that is, two or more parallel actions can be naturally merged into a parallel action according to their priority. We implemented several composite and parallel actions to demonstrate the viability of our approach.

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# 2 MODELING OF AGENT’S MOTIONS

## 2.1 Representation of Agent’s Body with Respect to Its Kinetic Functions

An agent’s major motions can be described in terms of the movements of its joints connecting its body parts. Therefore we model an agent’s body structure centered on its joints. We organize the body parts in layers according to their interdependencies in order to systematically express its kinetic composition and to implement the diversity of its motions at levels. Each connection point between body parts of an agent corresponds to its associated joint, and a primitive motion on a joint has an influence on its associated upper and lower body parts. If body part B is connected to body part A, a movement of A directly affects B, where A is called the upper part of B. The rotation direction of each joint generally consists of two planar directions and a torsional direction. The maximum rotation angle is set to the largest angle a joint can be rotated. Figure 1 sketches an agent’s structure as roughly modelled in terms of associated bones, with showing body parts and joints related to motions. The number in parentheses indicates the degrees of freedom for each joint.

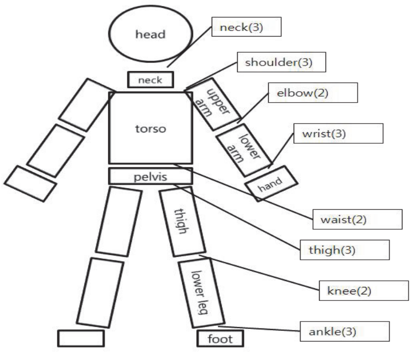

Figure 1: Agent's kinetic model.

According to the above kinetic agent model an agent’s mechanical body structure is organized into a hierarchical structure based on joints connecting body parts (Lee, 2009). This structure is of a pure tree to reflect the fact that no sequence of body parts forms a cycle. The highest body part, which affects all the other body parts, functions as the pivot for any complex motion or posture. We choose the pelvis as the highest body part since it functions as a pivot in many composite motions like ‘walk’ and ‘pitch’, and diverse postures like ‘sit’ and ‘stoop.’ Notice that the pelvis (and torso) is the only body part that is not dependent on any other part.

## 2.2 Formulation of Force Propagation from Upper Body Part to Lower Body Parts

Description of a hierarchical body structure in a model coordinate system is efficient for a situation where an agent has little interaction with external objects. In contrast a world coordinate system has advantages in detecting collisions with external objects (Wright, 2005). In a 3D model coordinate system an agent’s movement is described in terms of rotation and movement. The Euler Angle for the expression of a 3D space is a combination of three angles to specify the location of an object (James, 2006). The propagation of a force from a body part to its lower parts can be formulated as follows,

$$r_x(\alpha) = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{Bmatrix}$$

$$r_y(\beta) = \begin{Bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{Bmatrix}$$

$$r_z(\gamma) = \begin{Bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{Bmatrix}$$

$$r_{zyx} = r_z(\gamma) r_y(\beta) r_x(\alpha)$$

$$= \begin{Bmatrix} \cos\beta\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma \\ \cos\beta\sin\gamma & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma \\ -\sin\alpha & \sin\alpha\cos\beta & \cos\alpha\cos\beta \end{Bmatrix}$$

$$m_{\mathrm{i}} = r_z(\gamma) r_y(\beta) r_x(\alpha) t_{xyz}$$

$$= \left\{ \begin{matrix} \cos\beta\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma \\ \cos\beta\sin\gamma & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma \\ -\sin\alpha & \sin\alpha\cos\beta & \cos\alpha\cos\beta \\ 0 & 0 & 0 \end{matrix} \right. \tag{1}$$

Matrix $m_{\mathrm{i}}$ represents the sum of a movement operation on a body part and a rotation operation on a joint. Multiplication of a rotation matrix on a joint and a movement matrix on a body part produces a matrix to describe the overall body movement. Let $m_{\mathrm{k}}$ and $m_{\mathrm{i}}$ be position matrices on a body part and on the highest body part, respectively, the position of a body part is computed by a successive product of the position matrices on all of its upper body parts, that is, $m_{\mathrm{k}} = \{m_{\mathrm{i}-1} \times m_{\mathrm{i}-2} \times m_{\mathrm{i}-3} \times \cdots m_1\}$. While this model-coordinate-system-based method is intuitive and effective, it is hard to locate the collision positions among body parts. Hence, we converts the actual position of a body part onto a world coordinate system for efficient modeling of an agent’s intraction with the external objects.

# 3 MODELING OF PRIMITIVE MOTIONS

The movements of the agent are classified into the primitive motions, composite motions, and actions. A primitive motion refers to a movement invloving only one joint, and a composite motion refers to one invloving two or more joints. An action refers to a sequence of motions for a specific goal. Many primitive motions may be assembled into a new motion. By performing its motions an agent attempts to change a given situation toward a goal state. A process to arrange those motions into a schedule is an extension of a process to form a composite motion out of many primitive motions.

The process to move from an initial state to a goal state is visualized using a method that exploits afterimage of stagnant objects as in animation. To effectively create and render diverse motions, our method expresses the dynamic movement by changing the angle of a joint with setting a key frame as the goal state the instant that the agent initiates a motion (Ryu, 2008; Choi, 2006). The motion capture method is analogous to an implementation method based on a world coordinate system in that it computes the length of a body part and the angle of a joint using an interpolation with respect to some selected points of the body. In a virtual world without hardware supports, it is impossible to continuously attain the values on the length of a body part.

The effect of a motion is decided according to a goal state assigned to the function for moving its associated joint. These functions are to be executed independently of each other for real time execution. The resulting movement of the body part could be portrayed as a gradual change in the angle of a joint involved in the motion. This control of a body part is formulated as,

$$\prod_{i}^{n}(f : \alpha_i \rightarrow m_i) \tag{2}$$

where Π denotes a temporal sequence, $\alpha$ denotes an angle of a joint, and $m$ denotes a primitive motion.

# 4 MODELING OF ACTIONS

## 4.1 Structure of an Action

A set of the primitive motions is predefined for each joint, and some of them on different joints are assembled in parallel sequences to form a composite motion. Those composite motions may be arranged into an action. An action is performed by iterating a primitive or composite motion or executing a sequence of motions. A primitive motion in an action is defined as a phase, and a set of parallel primitive motions constitute a composite phase. A state S changes as a result of executing the motions $m_j$ in an action.

$$S(t + \Delta t) = S(t) + \prod_{i}^{M}\left(\sum_{j}^{N} m_j^i, \mathit{such\ as}\ \mathcal{A}_s \supset m_j^i\right) \tag{3}$$

Where $S$ denotes a state, $m$ denotes a motion, $\mathcal{A}$ denotes an action, $M$ denotes the number of phases and $N$ denotes the number of motions in each phase, ∏ denotes a phasic development and Σ denotes a set of parallel motions.

## 4.2 Synchronization for a Composite Motion

For realistic construction of a composite motion all the movements of the body parts involved are to be synchronized. The angular velocity of each joint used in the motion is adjusted in proportion to the distance from the initial state to the goal state. As a result every motion in an action is executed in the same time interval. Fig. 2 illustrates a state change in the body parts involved in a composite motion of ‘walk’. To briefly narrate, Leg L steps on the ground, then Leg R steps forward along with its pelvis. According to the hierarchical structure of body composition, all its body parts simultaneously move by 3 units. The Length 1 in Leg L’s movement by the joint’s rotation indicates the distance up to the point the foot stands perpendicular to the ground in reference to the pelvis. The Length 2 indicates the distance Leg R moves from the point it is perpendicular to the pelvis after Leg R steps on the ground. If the distance Leg R moves due to the joint’s rotation does not match the sum of Length 1 and Length 2, the speed the feet step on the ground would not synchronize with that of the overall body, resulting in an unnatural action.

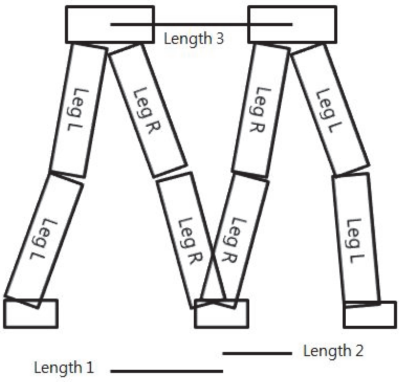

Figure 2: Synchronization of motions in walking.

## 4.3 Planning for Actions

The movement in a motion has directivity with respect to initial state and goal state. In a 'walk' occurrence, for example, the angle of a joint controlling the arms and legs could be described in terms of movement of a single rotation pivot from an initial state to a goal state. A real human's motion in practice involves not only a pivot for a major rotation but other pivots for auxiliary rotations (Calvert, 1989). Because a primitive motion only proceeds in one direction, the number of composite phases in an action is determined according to the number of changeable directions. In case of a repetitive action where different motions may end at different times, the number of composite phases accordingly increases. If performing a composite action of 'walking' and 'eating' in parallel, an arm used for eating may end its motion at a moment different from that for walking. Hence, we divide the goal state of a joint's motion into composite phases (Winston, 1992). The minimum time unit in which an action with composite phases is described is Δt, which is defined to be a temporal difference between mismatching motions.

## 4.4 Precision of Action

The precision of an action is determined by the number of composite phases in the action. When the required degrees of precision differ among different body parts each body part needs to be divided in the finest unit for their synchronization. The precision of an action could be gauged by,

$$x = \frac{\sum_i^n d_i \left(\sum_j^n m_j^i\right)}{T} \tag{4}$$

$d_i$ denotes the maximum directivity of a composite phase, $m_j^i$ denotes the directivity of body parts involved in an action during its performance time, $T$.

## 4.5 Combination of Actions into a Parallel or Concurrent Action

A parallel action refers to a composite action which performs two or more individual actions at the same time. We implement a parallel action by combining actions instead of assembling primitive motions. Those actions are implemented in terms of composite motions. When combining two individual actions we need to evaluate the priority between them for each body part, which is to be used exclusively by either one of the actions. Such a priority could be compared between the actions to be combined using Table 1.

Table 1: Relative priority between actions on body part.

| Action 2<br>Action 1 | Null | Optional | Essential |
|---|---|---|---|
| Null | Not applicable | Action 2 | Action 2 |
| Optional | Action 1 | Toss-up | Action 2 |
| Essential | Action 1 | Action 1 | Impossible |

As for a parallel action of 'eating while walking', an essential motion for 'walking' is a motion on each leg with a motion on each arm optional in an auxiliary role. Those stagnant parts like the torso and the head are judged irrelevant to walking. Likewise the essential motions for 'eating' include those on the mouth and an arm and all the other motions are irrelevant. Because their essential motions do not overlap each other those two actions could be combined into a parallel action.

If two actions are not compatible for a parallel action, they can still be concurrently performed. A concurrent action refers to performing two or more independent actions alternately at a high frequency. Those independent actions cannot be executed simultaneously but they take turns to be completed at the same time or to effectively proceed in parallel. The difference of a concurrent action from a composite motion is that it considers only two motions on a body part where a concurrent action is not possible to be performed.

To construct a parallel action its associated motions need to be described in the same unit of body parts. That is, each unit is associated with a function. A composite motion can be modelled in terms of the arms, legs, torso and head, or of a dichotomy between the upper and lower bodies.

$$\mathcal{M} = (\mathcal{P}_{\mathrm{n}}, \mathcal{P}_{\mathrm{n+1}}, \mathcal{P}_{\mathrm{n+2}}, \mathcal{P}_{\mathrm{n+3}} \cdots \mathcal{P}_{\mathrm{n+k}}) \qquad (5)$$

where $\mathcal{P}_{\mathrm{n}}$ denotes a functional body part on level $n$ in a hierarchical structure as arms, legs.

The body parts have connection links to transfer mechanical force. A composite motion needs to include the body parts connected via those links. With $\mathcal{P}_0$ the highest body part, the body parts as the functional units of a composite motion are connected from $\mathcal{P}_{\mathrm{n}}$ to $\mathcal{P}_{\mathrm{n+k}}$.

## 5 INTERACTION BETWEEN OBJECTS VIA ACTIONS

An interaction between objects is preceded by a spatial collocation or collision (Kim, 2012). We model states just as realistic as they can be recognized so we can avoid using a physics engine to detect collisions like in a computation heavy game. We classify the objects in our cyber world into the active objects and the passive objects. An active object like a human not only behaves autonomously but induces reactions from other objects. That is, it sends a message to other objects to perform an action.

To handle the actions of all the objects in the cyber world a multi-tasking control mechanism is needed. Even though all the motions on a scene look independent they technically belong to a single task requiring no context switching. A state of our cyber world resulting from the effect of many agents' actions could be formulated by extending (3) as,

$$S_k = \sum_{i}^{n} p_i \left( \prod_{q}^{n} \left( \sum_{j}^{n} f\left(a_j^q\right) \right) \right) + S_{k-1} \qquad (6)$$

$p_i$ denotes the agents, and the other notations are referred to (3).

## 6 IMPLEMENTATION OF EXAMPLE MOTIONS AND ACTIONS

We implemented our method based on the reuse of motions and superimposition of composite motions to realize parallel actions. We demonstrate the viability of our method through several actions such as 'walk', 'open' and 'eating while walking'. 'walk' is a basic action implemented as an iterative composite motion. 'open' is an action involving an interaction between an agent and a door. 'eating while walking' is a parallel action between 'eat' and 'walk'. Our implementation tools included Visual studio 2008 and OpenGL, along with the Microsoft Access 2007 as the database environment.

An agent performs a movement by executing 'walk' motion iteratively toward the goal location. Even though the distances from the initial state to the goal state differ between the arms and the legs, a walking action naturally proceeds by their synchronization.

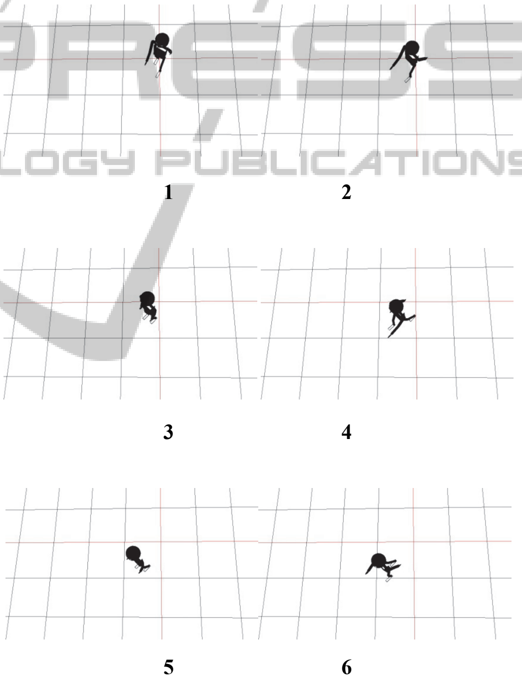

Figure 3: A Sequence of motions for walking.

An active object interacts with other objects by sending a message to them. The following sequence of scenes show an agent opens a passive object of a door by exchanging messages.

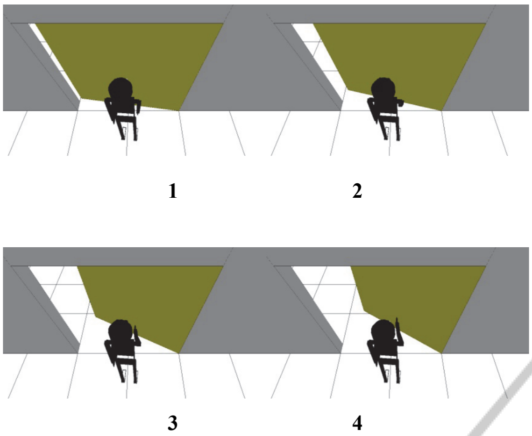

Figure 4: A Sequence of motions for opening a door.

In a real situation, it is an important capability to react to an abrupt change in state. Such capability of our method is used to efficiently implement parallel and concurrent actions.

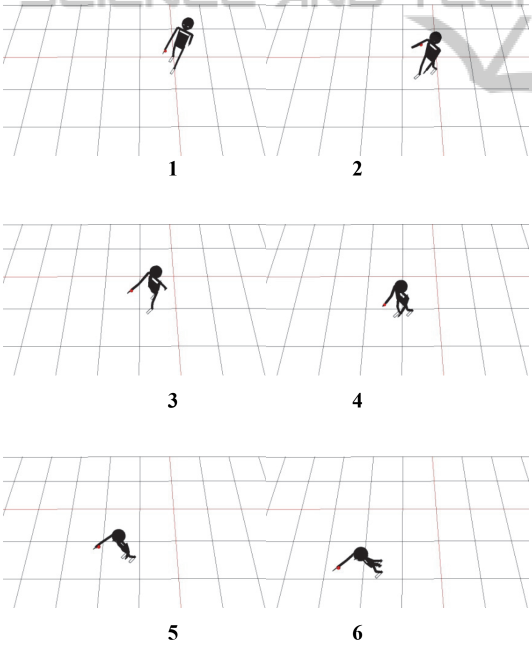

Figure 5: A Sequence of motions for eating while walking.

We show an agent is walking eating something. We superimposed an eating motion on top of a walking motion instead of assembling the primitive motions. That superimposion is determined by the priority table.

A concurrent action can be implemented using the same method that is used for a parallel action. The resulting scene is visually equivalent to an iterative composite motion.

# 6 CONCLUSION

We have developed an efficient scheme for implementing a diversity of actions to be performed by agents in a virtual world. We first defined a set of primitive motions and combined them into composite motions. Those primitive motions are reused to construct concurrent and parallel actions, and their associated design method enables an agent to instantly react to changes in its ambient states. Specifically an agent's body was modelled in terms of joints, and a primitive or composite motion can be performed in a real time. We produced an animation for basic joint movements and developed a method to construct overall motions out of the primitive motions. These motions can be assembled into a plan by which an agent can achieve a goal. In this manner, diverse actions can be implemented without excessive efforts. This approach has a conspicuous advantage when constructing parallel actions, e.g., eating while walking. Two or more actions as they are can be merged into a parallel action according to their priority. We traded some visual realism off to accomplish an efficient implementation of complex actions. To demonstrate the viability of our scheme we implement several actions of different types of complex actions. A composite action of 'walk' was shown to be implemented by iterating a composite motion and an interactive composite action of 'opening a door' was shown to allow an agent to interact with an external object of a door by sending a message. A parallel action of 'eating while walking' was implemented to show how two composite actions of eating and walking can be superimposed as they are to construct a parallel action.

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