ABSTRACT

LEE, SEUNG YONG. A Framework for Real-time Synchronization in Intelligent Media Generators. (Under the direction of James C. Lester.)

Recent advances in computer graphics and multimedia technologies have contributed to the development of interactive media-rich systems that generate media elements dynamically in multiple modalities to present information in an effective and appealing manner to users. Utilizing media elements in an application that requires them to be temporally coordinated in real-time presents synchronization issues because the wrong timing or duration of media elements will be easily detected by the user. Most media-rich systems have solved various aspects of the media element synchronization problem. However, they have done so in an *ad hoc* manner without providing a generic reusable framework. This thesis proposes a framework for real-time synchronization in intelligent media generators. Our research addresses six primary issues that are essential to creating media-rich systems that do not utilize an *ad hoc* solution to their media element synchronization problems: synchronization of media elements, decoupling high-level and low-level processing, extensibility, media element sequencing, real-time performance, and domain-independence. The framework has been implemented in an agent-based multimedia generator for an intelligent tutoring system to demonstrate its feasibility.

A Framework for Real-time Synchronization in Intelligent Media Generators

by

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BIOGRAPHY

Seung Yong Lee was born in Pusan, South Korea in 1970. He immigrated to the United States in 1987. After graduating from high school he attended North Carolina State University and received a Bachelor of Science in Chemical Engineering and Pulp and Paper Science Technology in 1997. He decided to move to a new career in Computer Science after working in industry for a few years. He began his graduate studies at North Carolina State University in the Department of Computer Science and joined the IntelliMedia Initiative. He looks forward to continued success in his new field.

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1 Introduction

For the past decade, intelligent media generation has been the subject of increasing attention. Researchers have investigated systems that can dynamically create and sequence media elements in multiple modalities to present information in an effective and appealing way to the user. Two primary areas of research that have received much attention are the study of embodied animated agents and intelligent multimedia presentations. Systems within both of these areas of inquiry convey information using multiple media elements from multiple modalities, such as speech, text, sound, and animations. A common problem that exists for each of these systems is the need to properly synchronize and schedule dynamically generated media elements. Any irregularities in the synchronization of these elements are likely to be noticed by the user, which could significantly degrade the overall effectiveness of the system. However, little attention has been placed on developing a generic framework for properly handling the synchronization and scheduling of dynamically generating media elements.

An embodied animated agent is a life-like character embedded in a user interface with the capacity to interact with users both verbally and nonverbally (Cassell, 2000; Lester *et al*., 1999). STEVE is an animated pedagogical agent, inhabiting a virtual learning environment for the domain of team training, which provides real-time spoken and

animated advice to learners (Rickel and Johnson, 1997). If the media elements associated with the agent's behaviors are inappropriately synchronized, the wrong information might be conveyed to the user, which would result in an ineffective learning experience. For example, during a training exercise, if the learner is uncertain about the next step and asks STEVE for advice, he might respond with, "I suggest you press the function test button," while also using a pointing gesture to clearly disambiguate the function test button among other buttons. If the pointing gestures were not properly synchronized with the utterance, the learner might become confused.

Intelligent multimedia presentation systems (André *et al*., 1993; Daniel *et al*., 1999; Feiner and Mckeown, 1993; McKeown *et al*., 2001; Towns *et al*., 1998) dynamically assemble complex multimedia presentation from various media elements. Systems like these must provide proper media synchronization to ensure that the generated multimedia presentations are understandable to the listener. Personalized Plan-Based Presenter (PPP) generates multimedia explanations for a wide range of applications, including computer-based instruction, guides for information spaces, and Web-based product advertisement (André and Rist, 1996). For example, in the travel domain, PPP was used to prepare multimedia presentations regarding destinations such as cities and hotels. Using photos, animations, and speech the system prepared a customized presentation to help users learn more about their destinations. If the photos, animations, and speech were not properly synchronized, the resulting presentation would be very ineffective.

All of the above media-rich systems have solved some aspects of the media element synchronization and scheduling problem. However, they have done so in an *ad hoc* manner

without providing a generic reusable framework. Since all intelligent media generators require a synchronization and scheduling component to convey information effectively and appropriately to the user in a real-time environment, a generic framework for multimedia synchronization with well-defined interfaces would significantly benefit media-rich generation applications. This type of component can be utilized in a wide variety of interactive systems, including virtual reality training, education, simulation, and entertainment applications.

1.1 Overview of Research

For interactive systems that utilize dynamically generated media elements to be easily created and properly maintained, it is useful to partition the synchronization and scheduling into high-level and lower-level processing components operating as separate entities with well-defined interfaces. Properly decoupled components do not need to know how their requests are created or where they are executed. In particular, the high-level processes should communicate with lower-level processes through media element specifications. These media element specifications provide abstract information regarding which elements should be executed and when they should be executed relative to other elements. This is similar to the approach taken by Pelachaud for the Affective Presentation Markup Langauge (APML) to decouple the specification of facial expressions and facial models (Pelachaud and Bilvi, 2002). It is the responsibility of the lower-level processes to handle the detailed media element synchronization, generate appropriate media element sequences to complement other elements, and schedule generated elements upon receiving

the specifications. In this thesis, we propose a generic framework for handling these lower-level responsibilities. Specifically, the proposed framework has the following goals:

- *Synchronization*: Because timing is essential in conveying information during communication, the framework should provide tight synchrony among the various communicative modalities.

- *Decoupling*: The communication between high-level and lower-level coordination processes should occur via well-defined interfaces using media element specifications and event notifications.

- *Extensibility*: The entire framework should be modular and extensible enabling new modalities to be added to the framework with ease without affecting other media element components.

- *Media Element Sequencing*: Because the high-level media element specifications provide only abstract information for selecting elements, the framework should be able to select appropriate sequences of elements based on the current state of the environment.

- *Real-time Performance*: To provide the responsive interaction required by interactive environments, the framework should operate in real-time.

- *Domain Independence*: The framework should be adaptable to diverse domains. As long as knowledge of the current domain is available, the process of handling media elements should be the same.

The proposed framework has been implemented in the PHYSVIZ test-bed application. PHYSVIZ is a 3D learning environment for the domain of physics focusing on concepts of electromagnetism. Users interact with the system via an embodied animated

pedagogical agent. The job of the agent is to answer questions from the user by describing how battery-operated motors work. The agent is a life-like character with a fully articulated body that communicates with the user using verbal and nonverbal behaviors. In the process of describing how battery-operated motors operate, the agent uses coordinated speech utterances and gestures. Figure 1-1 shows the PHYSVIZ system.

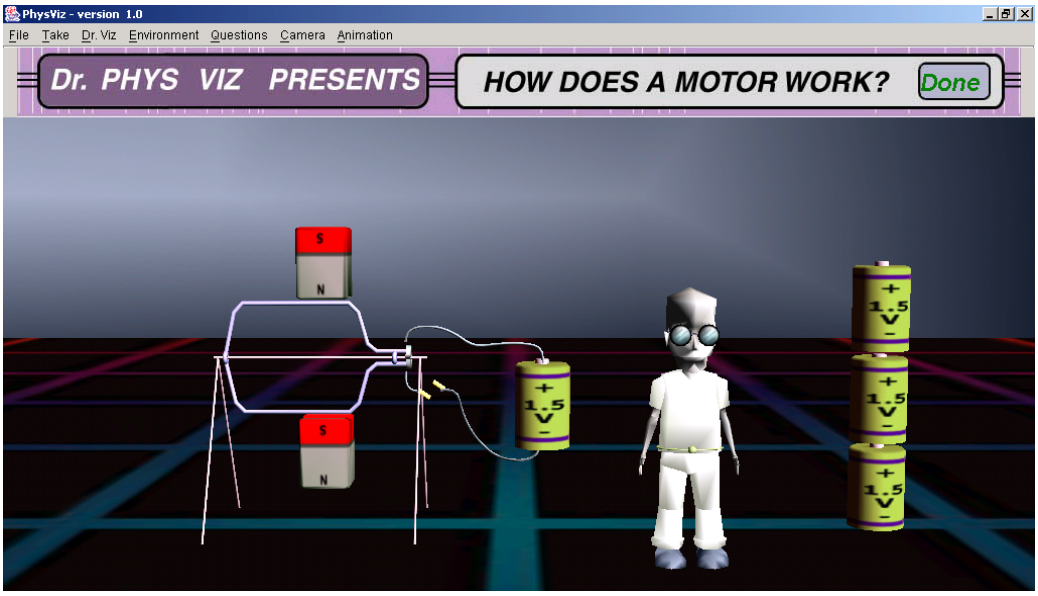

Figure 1-1: PhysViz – A 3D Learning Environment

1.2 Thesis Organization

Chapter 1 provides an introduction to the problem and an overview of the research goals. In Chapter 2, the detailed research problem and motivation is discussed. Chapter 3 presents a description of the framework's architecture for the synchronization of media elements in a real-time environment. Chapter 4 provides details associated with the PHYSVIZ test-bed system. This chapter discusses the low-level details of the implemented architecture and gives a number of example scenarios. Chapter 5 examines related work

and demonstrates how the framework can be applied to other systems. The final chapter concludes the thesis and proposes future work.

2 Issues in Multimedia Synchronization

Due to the advancements in computer graphics and multimedia technologies, the life-likeness of embodied animated agents and the richness of intelligent multimedia presentation systems have greatly improved over the last few years. A growing number of character animation tools and systems are capable of creating very realistic gestures, facial expressions, and body language. Also, some systems use these realistic life-like characters along with virtual cameras, speech, and text. However, the synchronization of media elements in these multimodal environments presents a significant problem. Utilizing media elements in an application that requires them to be temporally coordinated in real-time presents synchronization issues because users will easily detect the wrong timing or duration of media elements. Most of the existing media-rich systems have solved various aspects of the media element synchronization problem. However, they have done so in an *ad hoc* manner without providing a generic reusable framework.

2.1 Importance of Synchronization in Media-Rich Systems

In everyday interaction, people exchange information by participating in conversations. In face-to-face conversations people use gestures, facial expressions, gaze, and body movements in addition to their actual speech to disambiguate, emphasize, and provide additional information to the listener. Such nonverbal behaviors are a fundamental

part of a conversation, and it is difficult to imagine separating them from their corresponding verbal behaviors and retaining the same level of communicative effectiveness. Furthermore, people instinctively synchronize the gestures and facial expressions with speech easily and naturally in their daily conversational activities. However, if these verbal and nonverbal behaviors are inappropriately synchronized or the wrong behaviors are selected then the participants in the conversation might receive incorrect information and become confused. Because humans are accustomed to communicating in this manner, any irregularities with the behavior synchronization and selection will be very noticeable and distracting. These same issues are present when humans interact with embodied animated agents as they become increasingly believable and life-like.

Believability is a key feature of all animated agents. A believable character is one who seems life-like, who is able to express emotion, and whose actions make sense, thus allowing users to suspend disbelief (Bates 1994; Mateas 1997). Humans naturally synchronize and select gestures with speech during communication and change facial expressions as emotion changes. If media elements for an animated agent are not properly synchronized and scheduled, believability will be greatly reduced.

Synchronization is an essential feature for an animated pedagogical agent. In interactive learning environments, the presence of a life-like animated agent can provide positive influences on student's learning effectiveness (Lester *et al*., 1997). However, if media elements are not properly synchronized then the life-likeness of the agent is weakened. If the animated agent describes one thing and points to another or if the agent

makes a gesture for no apparent reason then the user might get the wrong idea and become confused which would result in an ineffective learning experience.

Synchronization also serves an important role in intelligent multimedia presentation systems (IMMPS). An IMMPS has a library of accessible media elements and presentation methods. By using a combination of these alternative media and presentation techniques, IMMPSs provide a rich means of communicating information to users through their presentations (Roth and Hefley, 1993). To attain correct communicating information, the system must provide proper media synchronization. If the media elements associated with the multimedia presentation are inappropriately synchronized, the effectiveness of the presentation will be greatly reduced.

2.2 Approaches to Synchronization Specification

To facilitate modularity and extensibility, a media element specification language can be used. For example, VHML (Virtual Human Markup Language) is used to allow interactions between users and a virtual human by providing several sub-languages for each virtual human modality (Beard and Reid, 2002). FAML is for facial expression, SML is for speech, EML is for emotion, and GML is for gesture. The MPML (Multi-modal Presentation Markup Language) is an XML-based language used to control characters for multimedia presentations on the World Wide Web (Ishizuka *et al*., 2000). The BEAT (Behavior Expression Animation Toolkit) system enables animation of agents. It generates appropriate gestures and facial animations for speech generated from typed text (Cassell *et al*., 2001). The BEAT system is used in MACK (Cassell *et at*., 2002). MACK is an embodied

conversational agent who can give directions to the MIT Media Lab research groups and people. LEA (Busine *et al*., 2002) is a 2D embodied agent project that uses specifications to annotate human multimodal behaviors. The specification is based on the Tycoon typology (Martin *et al*., 2001) for natural agent behavior. These systems have tried to decouple the high-level and lower-level coordination processing components. However, their work has focused on the specification language and not the lower-level synchronization issues.

2.3 Criteria for Building a Generic Framework

Various aspects of the media element synchronization and scheduling problem have been solved by existing media-rich systems. However, they have done so in an *ad hoc* manner without providing a generic reusable framework. In order for media-rich systems to have such a framework, six fundamental issues must be addressed:

1. *Synchronization of media elements*: Since interactive media-rich environments have multiple modalities, it is crucial that media elements are synchronized to deliver the correct information at the proper time. For example, COSMO (Lester *et al.*, 1999), an animated pedagogical agent, inhabits a learning environment for the domain of Internet packet routing and provides real-time spoken and animated advice to learners. If the agent would like to point out two computers and indicate that one has low traffic and the other one has high traffic then he might say, "This one has low traffic and that one has high traffic," while also using pointing gestures to clearly disambiguate the two computers. In this case, if the pointing gestures did not properly synchronize with the utterance of "this one" and "that one" the learner might become confused. PLANT WORLD (Daniel *et al.*, 1999) generates multimodal explanations for botanical anatomy and physiology in a 3D learning environment. It generates visual and verbal explanations to answer questions posed by users.

Suppose the system is beginning to explain the role of chloroplasts. The generated verbal explanation might be "The chloroplasts produce food sugars for the plant. Food sugars are used throughout the plant for energy," while the visual explanation might have the virtual camera show the chloroplasts and an animation of food sugars. Once again it is important for these different media elements to properly synchronize.

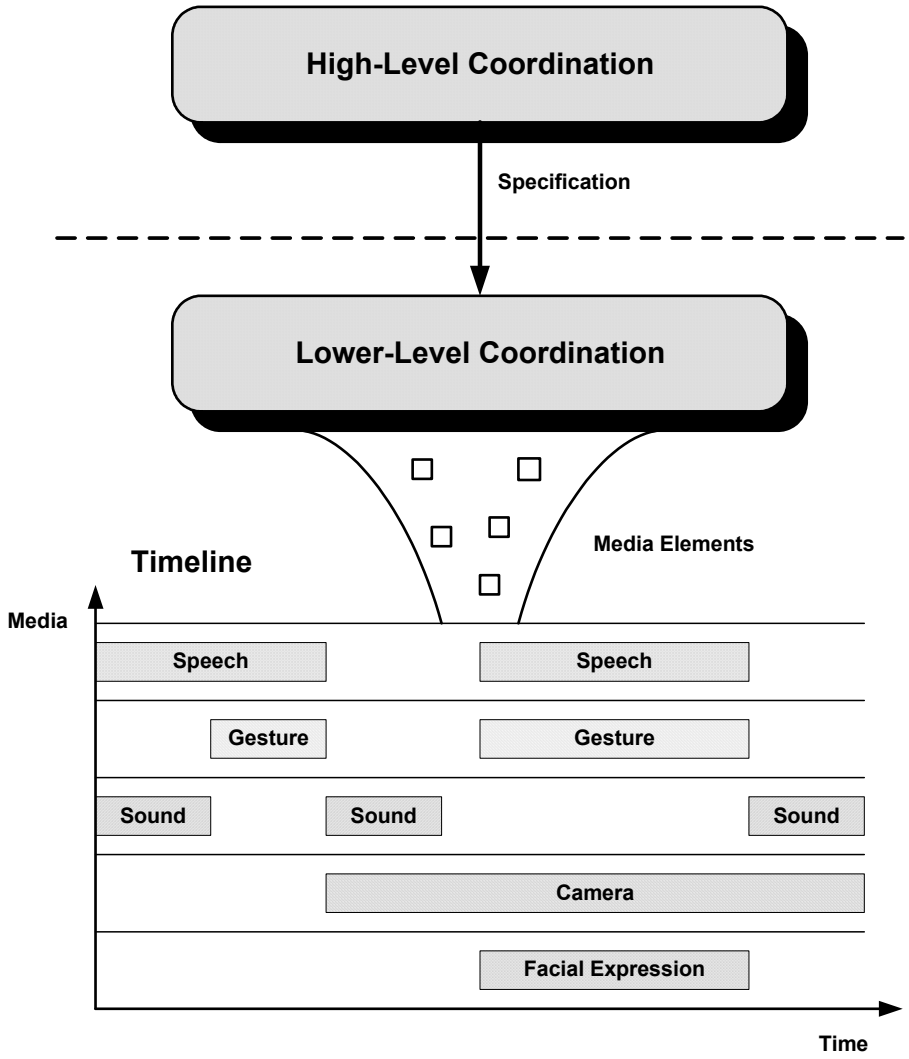

Figure 2-1: Separation of High-Level and Lower-Level Coordination

2. *Decoupling*: Decoupling components within a complex system is an important feature when building a generic framework. By separating high-level and lower-

level processing components and clearly defining their operation, media elements can be easily created and properly maintained as shown in Figure 2-1. The components operate as separate entities and communicate thru well-defined media element specifications. Low-level components generate appropriate media elements and display them in a synchronized manner. Since the only communicative activity is through media element specifications and event notifications, the low-level processing components can be used in any media-rich system as long as the high-level processing components provide the proper specifications.

3. *Extensibility*: The framework should be modular and extensible, enabling new modalities to be added to the framework with ease without affecting other media element components. For example, consider a system that is capable of generating speech and gesture media elements for an embedded animated agent. If the system needs to incorporate facial expressions along with speech and gestures for an animated agent to express emotions, the speech and gesture components should not be affected by the additional facial expression modality. Also, the specification language only needs to be extended to include the appropriate tags (assuming it is an XML-like language).

4. *Media Element Sequencing*: The media element specifications should contain abstract information regarding which media elements should be executed and when they should be executed relative to other media elements. It is the lower-level processing component's responsibility to select the appropriate media elements for the current context. Imagine an animated agent inhabiting a learning environment who tries to describe a battery-operated motor to the learner. If the agent would like to point out the motor's magnets and batteries then the specification could include associated speech and abstract gesture information. For example, the speech for the agent might be, "Here are the motor's magnets and its batteries," while specifying pointing gestures to clearly disambiguate the magnets from the batteries. In this case, the specification does not define which deictic gestures to point out the

magnets and batteries. The low-level processing component selects the most appropriate deictic gestures and locomotion to properly point at the objects with the utterance of "magnets" and "batteries."

5. *Real-time Performance*: One approach to properly synchronizing the media elements in a media-rich environment is to have a group of expert animators pre-script all of the possible combinations of media elements. However, this method is very expensive, time-consuming, and in many cases impractical since it requires a large number of expert animators to cope with the combinatorics of producing context-sensitive media elements. In general it is impossible to anticipate all possible combinations of media elements to be displayed. A more practical approach is to dynamically generate appropriate media elements during runtime in a context-sensitive manner and synchronize them in real-time. The system should automate the process of determining media elements and their synchronization.

6. *Domain Independence*: By creating a domain-independent framework, the framework should enable the processing components to be reused for different applications with few modifications. As long as knowledge of the current domain is available, the process of handling the media elements should be the same.

A generic framework which addresses these six primary issues would be extremely useful for building future media-rich systems that do not utilize an *ad hoc* solution to their media element synchronization problems.

3 A Generic Framework for Real-Time Synchronization

For interactive media-rich systems to convey information effectively and appropriately to the user in a real-time environment, it is useful to partition the synchronization and scheduling of media elements into high-level and lower-level processing components working as separate entities with well-defined interfaces. To this end, a generic framework for low-level multimedia synchronization was developed to properly manage media elements as shown in Figure 3-1. A high-level processing component, such as a presentation planner or pedagogical planner, generates abstract media element specifications. These specifications are sent to the lower-level processing component to extract information and interpret them within the current context to generate the appropriate media elements. The generated media elements are then synchronized and scheduled for execution. The synchronized media elements are placed on a multimedia timeline to execute when the time is appropriate.

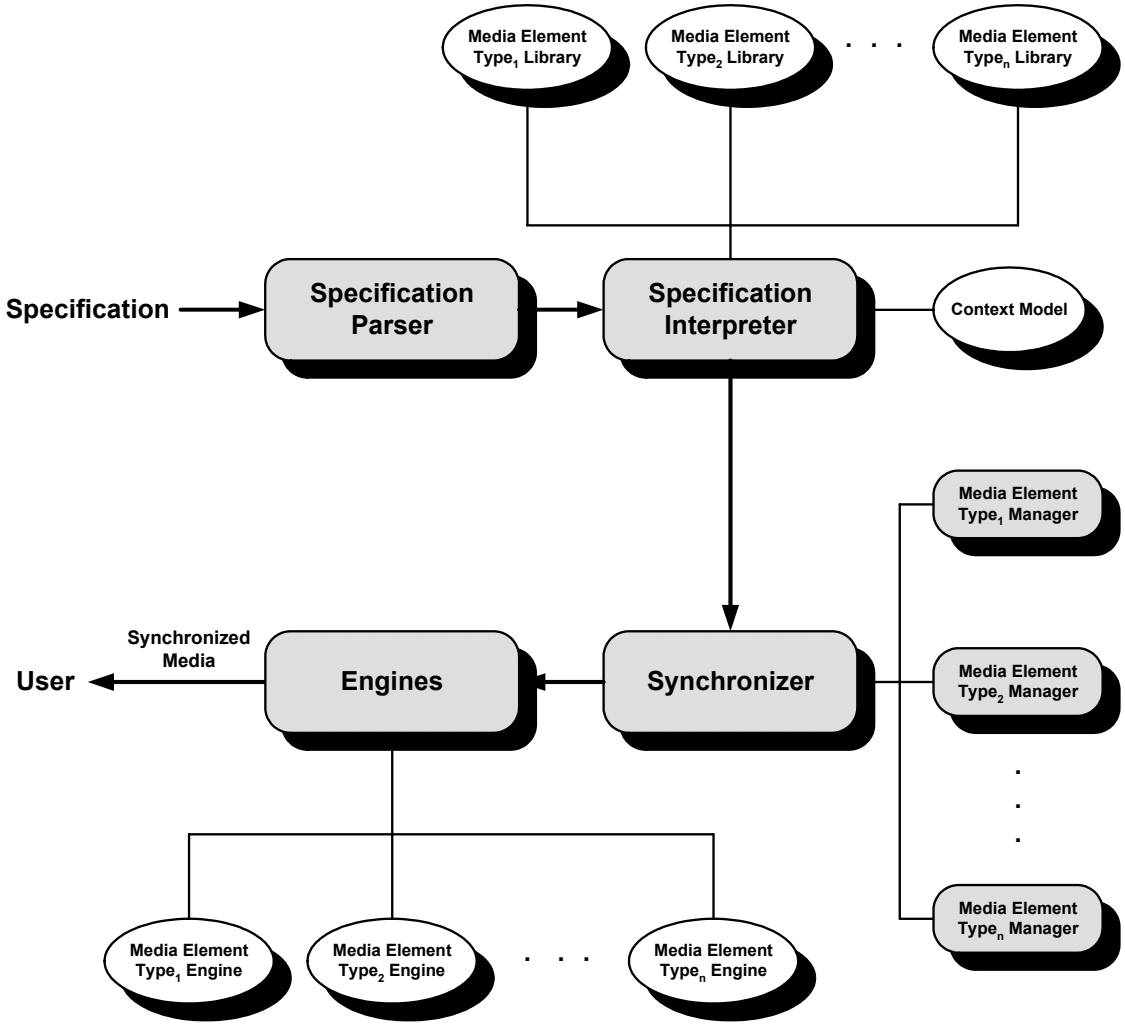

Figure 3-1: A Generic Framework for Multimedia Synchronization

3.1 Specification Parser

Because the high-level and lower-level processing components work as distinct entities, their primary communication is via media element specifications. These specifications are defined in an efficient way for annotations of multimodal behaviors. To represent the proper relationships of media elements, the specification uses an XML-based mark-up language. XML provides a natural way to represent media element information and allows new media element types to be added to the framework by simply extending the

media element specification language with the appropriate tags. Also, XML is a good choice for application developers since there are many tools available for parsing and generating XML text.

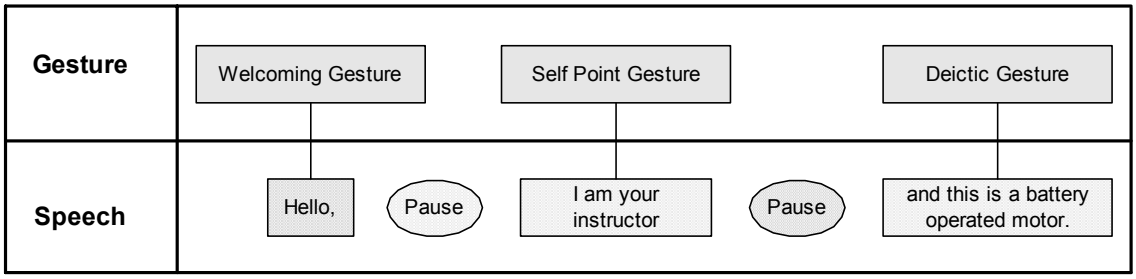

Figure 3-2: A Parsed Media Element Specification

The Specification Parser parses the abstract media element specification to determine what media elements need to be presented to the user. For example, a media element specification containing three speech clauses is shown in Figure 3-2. Each speech clause has an associated gesture specification, welcoming gesture for "Hello," self point gesture for "I am your instructor", and deictic gesture for "and this is a battery operated motor." In addition, there are speech pauses between each of the clauses. As shown in the figure, the specification contains abstract gesture information for each of the speech clauses. The specification encodes the focus object information along with other media elements to help with selecting the appropriate gestures. The parsed information is then sent to the Specification Interpreter to select and generate the appropriate media elements.

3.2 Specification Interpreter

Once the Specification Interpreter receives the parsed specification information, the interpreter analyzes the information and selects the appropriate media elements for the

current context. The input may contain abstract media element information along with their type, focus object, and dependents. In order to choose the appropriate media elements, the interpreter utilizes the available knowledge resources containing the necessary information to make appropriate selection decisions. In the previous example, the specification gave information about speech elements and the associated abstract gestures along with a corresponding focus object. With this information, the interpreter instantiates media elements for each of the media types by consulting the knowledge resources.

To select the most appropriate gesture element, the interpreter uses a context model. The context model provides the current state of the world geometries and key properties of world objects such as their location and orientation. Given the focus object and context model, the interpreter is able to select the most appropriate media element for the current context. For instance, the interpreter can create a sequence of media elements conforming to the abstract specification, which ensure that the results actions are seamless. If the focus of a pointing gesture were too far away, a walking behavior would be generated to walk over to the object and point as shown in Figure 3-3. Additionally, the interpreter determines the execution duration of the media elements. This duration helps with the synchronization process when one media element needs to finish its execution at the same time as an associated media element. Once all of the media elements have been determined, they are sent to the Synchronizer to properly synchronize and schedule them.

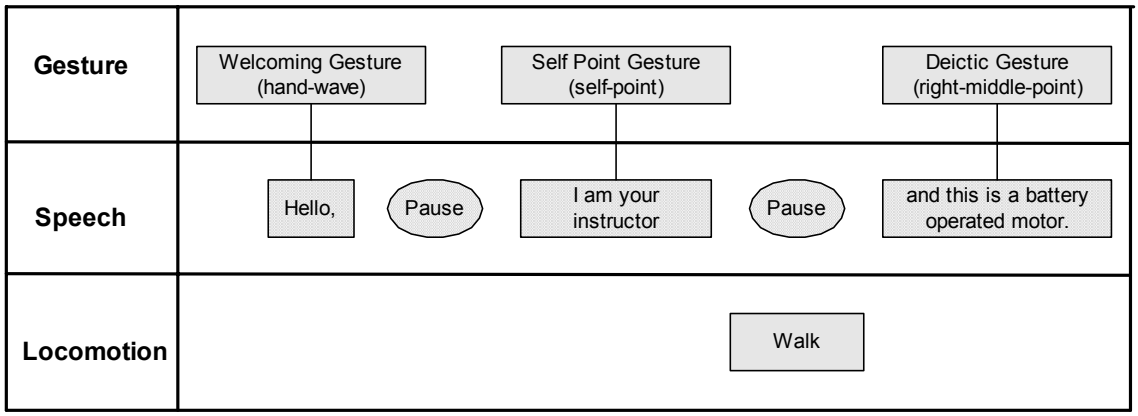

Figure 3-3: An Interpreted Media Element Specification

3.3 Synchronizer

To achieve the proper synchronization, the Synchronizer uses the media scheduler (a sub-component of the Synchronizer) and the media element managers to schedule each of the media elements. Upon receiving information from the interpreter, the Synchronizer distributes the media elements to their corresponding media element managers. Each media element has an associated set of media execution instructions contained in a library; however, the elements do not include information about how to invoke the media engine to execute these instructions. The media element managers place a wrapper object around the individual media elements to provide the needed interpretation trigger layer. Based on the trigger type, the media element engines decide whether to start, pause, or stop the current media element execution. The wrapper objects also include an execution notification mechanism. Whenever the media element starts or ends its execution, the wrapper object sends a notification to the media scheduler. This notification indicates to the media scheduler which media elements, whose activation time is dependent upon notified element's start or completion time, are ready for execution.

As the media element managers generate the wrapper objects for their corresponding media elements, the Synchronizer inserts these wrapper objects into the media scheduler based on the media element dependency information given in the specification. The media scheduler handles time-based scheduling, event-based scheduling, or a combination of these scheduling methods. For example, the media scheduler provides a mechanism to add a media element after an associated media element starts or stops. A mechanism is also provided which adds a media element after a specified time delay.

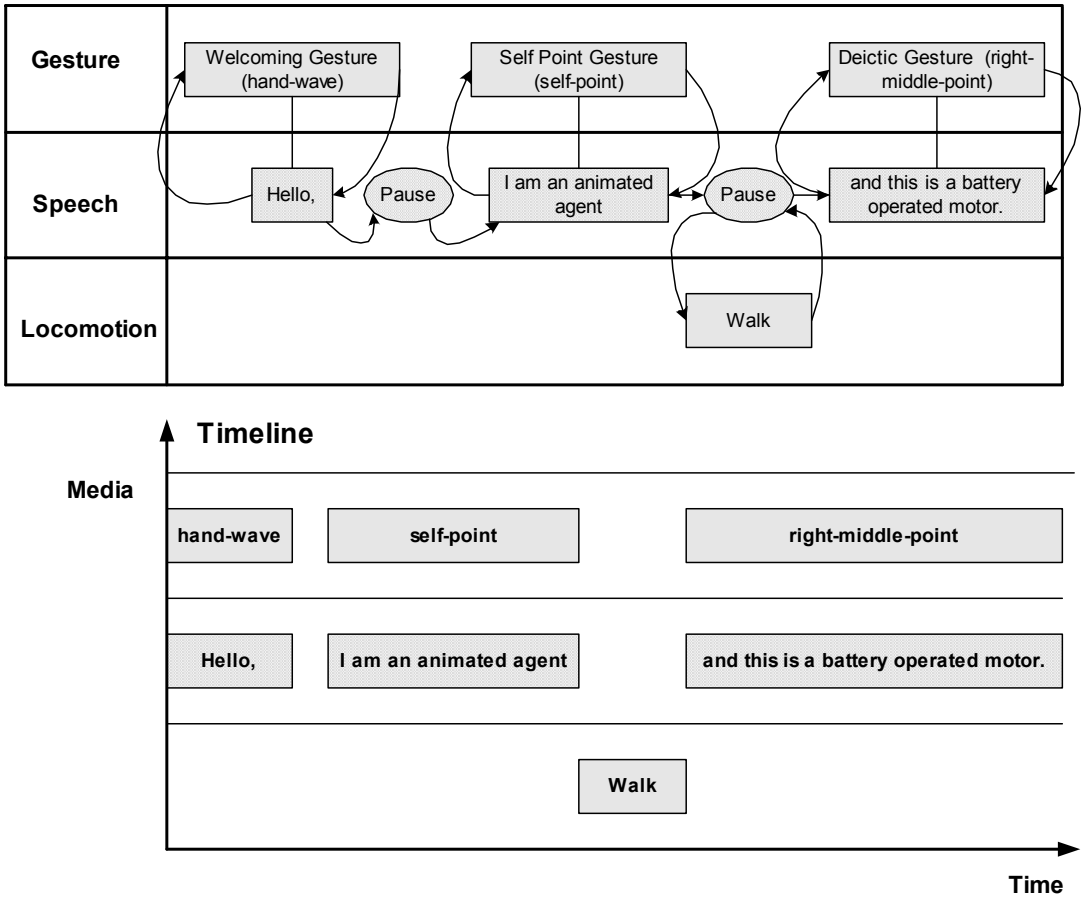

Figure 3-4: Synchronized Media Elements

Finally, the media scheduler also provides a mechanism to add media elements after a specified time delay relative to the start or end of an associated media element. Figure 3-4 shows the results of placing media elements from the previous example on a multimedia timeline for their execution.

3.4 An Animated Agent Based Framework

A generic framework for multimedia synchronization could help application developers make animated agents convey information more effectively and appropriately to the user in a real-time environment Since a generic framework facilitates modularity and extensibility, application developers can easily develop additional modules without affecting others. Figure 3-5 shows a framework design for an animated agent based system.

3.4.1 Specification Interpreter

The Specification Interpreter selects the most appropriate media elements, which ensure an animated agent's actions are seamless for the current context. In order to select the proper media elements, the interpreter uses five static knowledge resources that contain the necessary information to make selection decisions. Each knowledge resource includes instructions on how to execute the corresponding media elements.

- *Locomotion Library*: Provides the agent with movements that allow it to move from one place or orientation to another. Such movements include turning the agent's body and walking.

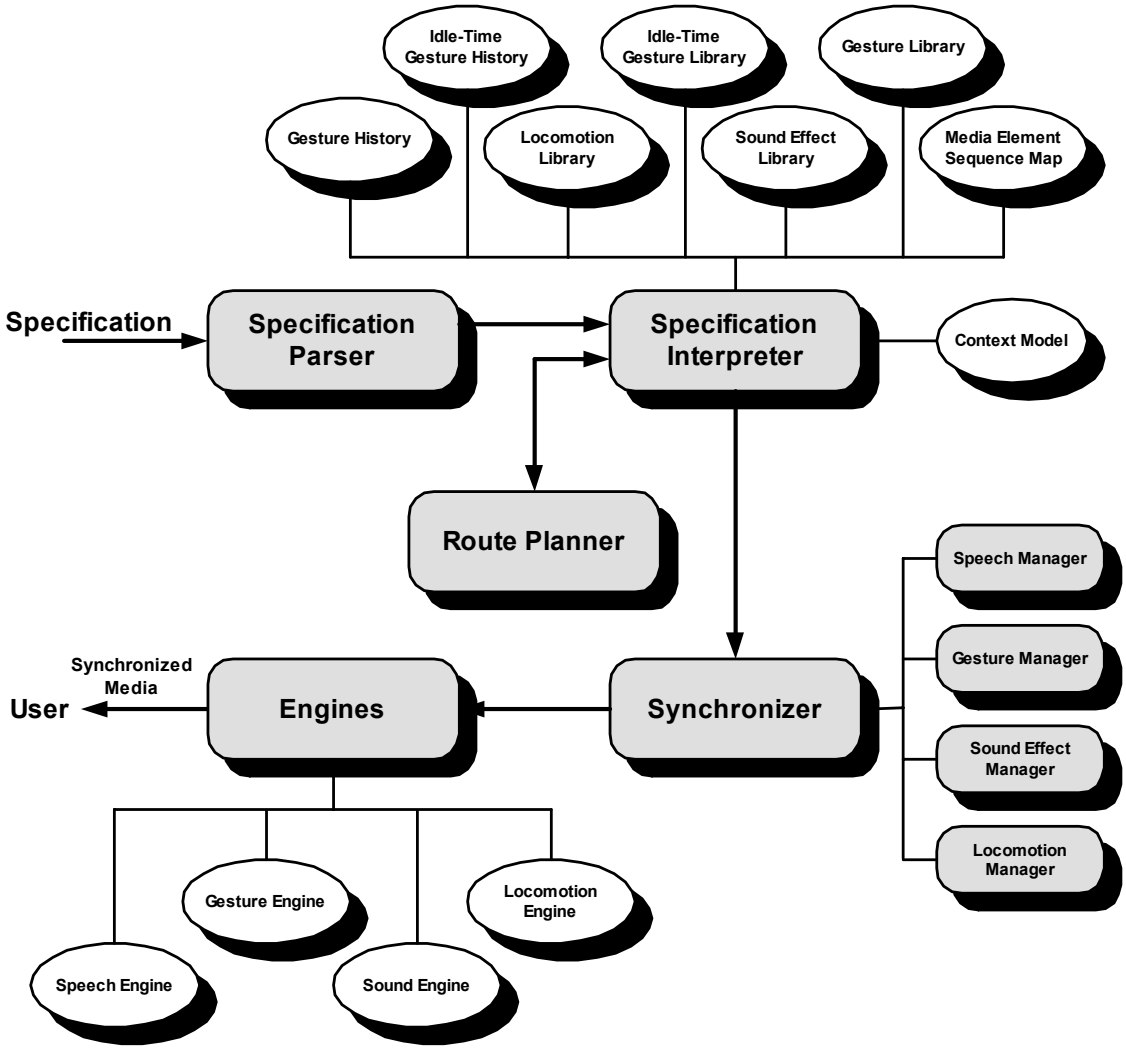

Figure 3-5: A Framework for Animated Agent Based Systems

- *Gesture Library*: Maintains agent gesture information. Some examples are hand waving, head turning, thinking, beat, and deictic behaviors.

- *Idle-Time Gesture Library*: Contains information about gestures, which are appropriate to use for idle-time behaviors, such as yawning, scratching, sneezing, brushing, stretching, and dancing.

- *Media Element Sequence Map*: At times the abstract specification represents more than one lower-level media element. This resource provides the mappings between such abstract media element specifications and the corresponding sequences of media elements.

- *Sound Effect Library*: Stores information about sound effects.

The framework also contains dynamic resources in addition to the above static resources. These resources are continuously updated as time passes. They constitute a comprehensive representation of the state of the world model and agent at any point in time.

- *Context Model*: Provides the current state of world geometries and properties of world objects. It also provides information about the agent's position and orientation.

- *Gesture History*: To prevent repeated occurrences of the same gesture, the gesture history keeps track of how many times a gesture has been selected.

- *Idle-Time Gesture History*: Provides randomness of idle-time gesture, the idle-time gesture history keeps track of how often each idle-time gesture has been selected.

Using these knowledge resources, the interpreter is able to translate the specifications and create sequences of media elements. The algorithm for generating the media elements is shown in Figure 3-6. First, the interpreter obtains the position and location of the agent and the focus object, respectively. This information helps to determine which gestures are appropriate to execute in the current world state. The interpreter uses the Media Element Sequence Map to convert the parsed specification into a

sequence of media element directives. Determining the sequence of media element directives is necessary since the high-level processing components provide abstract media element specifications. These abstract media element specifications might result in a combination of multiple media element directives.

I. Retrieve current location and orientation of agent and world model state.
II. For each remaining abstract media element specifications in set, in order,
  A. Given abstract information, interpret a specification into representation of media element sequences using the media element sequence map. If there is no corresponding mapping, use the given specification as a sequence containing one media element. Place the sequence of media elements in the given order of the media element sequence map.
  B. For each remaining media element directives in sequence, in order,
    a. If the directive is a sound, retrieve corresponding media element from sound library and add it to the media element list.
    b. If the directive is an idle-time behavior, retrieve all possible corresponding media elements where the agent can act appropriately for its current location and orientation from the idle-time gesture library. Using the retrieved idle-time gesture media elements, consult the idle-time gesture history to get a single idle-time gesture media element that has a least occurrence. Add it to the media element list.
    c. If the directive is a locomotion behavior, consult the locomotion library using the current agent location, orientation, and state of the world model to get the appropriate media element. Add it to the media element list.
    d. If the directive is an agent gesture, retrieve all possible corresponding media elements where the agent can act appropriately for its current location, orientation, and focus object from the gesture library. Using the retrieved gesture media element, consult the gesture history to get a single gesture media element that has a least occurrence. Add it to the media element list.
    e. If the behavior is speech behavior, generate the speech media element. Add it to the media element list.
    f. Determine execution duration of the media element.
  C. If all of the media element specifications in the sequence have been processed, add the list of created media elements into a result set.
  D. Send the resulting set of media elements to the Synchronizer

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Figure 3-6: An Animated Agent Based Specification Interpreter

Given the sequence of media element directives, the interpreter consults the corresponding knowledge resources to generate the most appropriate media elements. The interpreter also determines how long the media element should execute to meet the execution end time requirements.

3.4.2 Synchronizer

The media synchronizer plays an important role in the system. To make an agent life-like, media elements for an animated agent must be properly synchronized. Upon receiving media elements from the Specification Interpreter, the Synchronizer sends media elements to the corresponding media element managers. The media element managers create corresponding media engine triggers. These triggers are used as a communication mechanism between the media engines and media elements. The triggers allow for the communication of information such as when to start, pause, and stop media execution. Each of the resulting media elements is sent to the media scheduler to schedule their execution. The mechanisms for the basic process are given in Figure 3-7.

For each remaining set of media elements, in order,

A. For each remaining list of media elements in set, in order
  a. Separate media elements based on their media type.
  b. Send the separated media elements to the corresponding media managers to create triggering mechanisms for each of the media elements.

B. Once all of the trigger objects for the media elements have been determined, send them to the media scheduler to schedule their execution.

Figure 3-7: An Animated Agent Based Synchronizer

3.4.2.1 Media Scheduler

The resulting media elements produced by the Specification Interpreter are (need a different verb here but not sure what is meant) sent to the media managers where they determine the media engine triggering effects. *Start* and *end* media execution triggers are included in the media element. The Media Scheduler utilizes the presentation of each media element to schedule their execution. The basic scheduling mechanism is shown in Figure 3-8.

I. While new media elements exist in the scheduler, in order
- **A.** For each media element add it to the trigger dependent collection.
- **B.** If any of media element in the trigger dependent collection meets their activation criteria, add satisfied media elements into the corresponding resource-waiting queue.
- **C.** If any of the currently running media finish, send the corresponding media end notification trigger.
- **D.** If media resources became available, retrieve media element from resource waiting queue and invoke engine to start the new element. Send the corresponding media start notification trigger.

Figure 3-8: Media Scheduler

First, the scheduler inserts schedulable media elements into the trigger-dependent collection. This collection is the waiting place for media elements where they queue for their execution turn. Once the current media elements sends a start or end notification, the scheduler moves the notified media elements from the trigger-dependent collection into their corresponding resource-waiting queue. Media elements in the resource-waiting queue are ready for their execution and will be executed as soon as the resource is available. There is one resource-waiting queue per media type, such as gesture, speech, and sound. If a schedulable media element needs to execute immediately, the element is added to the

resource-waiting queue directly. After a media resource becomes available, a media element from the corresponding resource waiting queue is added to the resource and executed. As soon as the media element starts and completes execution, a notification is sent to the scheduler.

There are a few ways media elements can be added to the scheduler by a component. If a media element is dependent upon the start or completion time of another media element, a component can add the element to the scheduler by specifying its dependent media element. A component may also give an execution delay time along with the element's dependence. A delay time is a time period where execution of the element is delayed when the scheduler receives a start or end notification of the depended element. If a media element needs to be executed immediately, it can be added to the scheduler with no dependency and a delay time of zero.

Examples of media element scheduling are shown in Figure 3-9. These examples show how behaviors in each media element can be scheduled and executed. Figure 3-9(a) displays three batches of schedulable media elements. The first batch of media elements contains a gesture and speech element that starts and ends at the same time. The gesture element is depended upon the start time of the speech element. As soon as speech element starts its execution, the scheduler is notified and moves the gesture element into the resource-waiting queue. Since media resource is available, the gesture element is moved to the resource with no waiting and starts its execution as shown in Figure 3-9(b). Because the '*hand-wave*' gesture execution time is longer than the speech element '*hello*', the

system uses a frame-skipping technique to ensure that the gesture and speech end at the same time.

The second batch of media elements consists of one gesture and two speech elements. The gesture element contains a '*self-point*' behavior and the two speech elements contain '*I am an animated*' and '*agent*' utterances, respectively. All three media elements are currently in the trigger dependent collection. After receiving the end media notification of the '*hello*' speech element, the scheduler adds '*I am an animated*' speech element into the resource waiting queue. If the speech resource is available, the speech element moves into the resource and starts its execution. Upon receiving the media start notification, the scheduler also adds the '*self-point*' gesture element into the gesture resource-waiting queue. The gesture starts execution immediately since the gesture resource is available. The gesture resource ensures the gesture element ends with the currently running speech element. The speech element '*agent*' is added to the resource waiting queue and moves into the resource to start execution as soon as the '*I am an animated*' speech element finishes its execution as shown in Figure 3-9(c).

After some time, the scheduler receives the third batch of media elements. Since the speech element is not dependent upon other elements, it is added directly to the speech resource waiting queue and starts if the resource is available. The gesture element is added into the resource-waiting queue upon receiving the dependent speech media element start notification and is executed as shown in Figure 3-9(d).

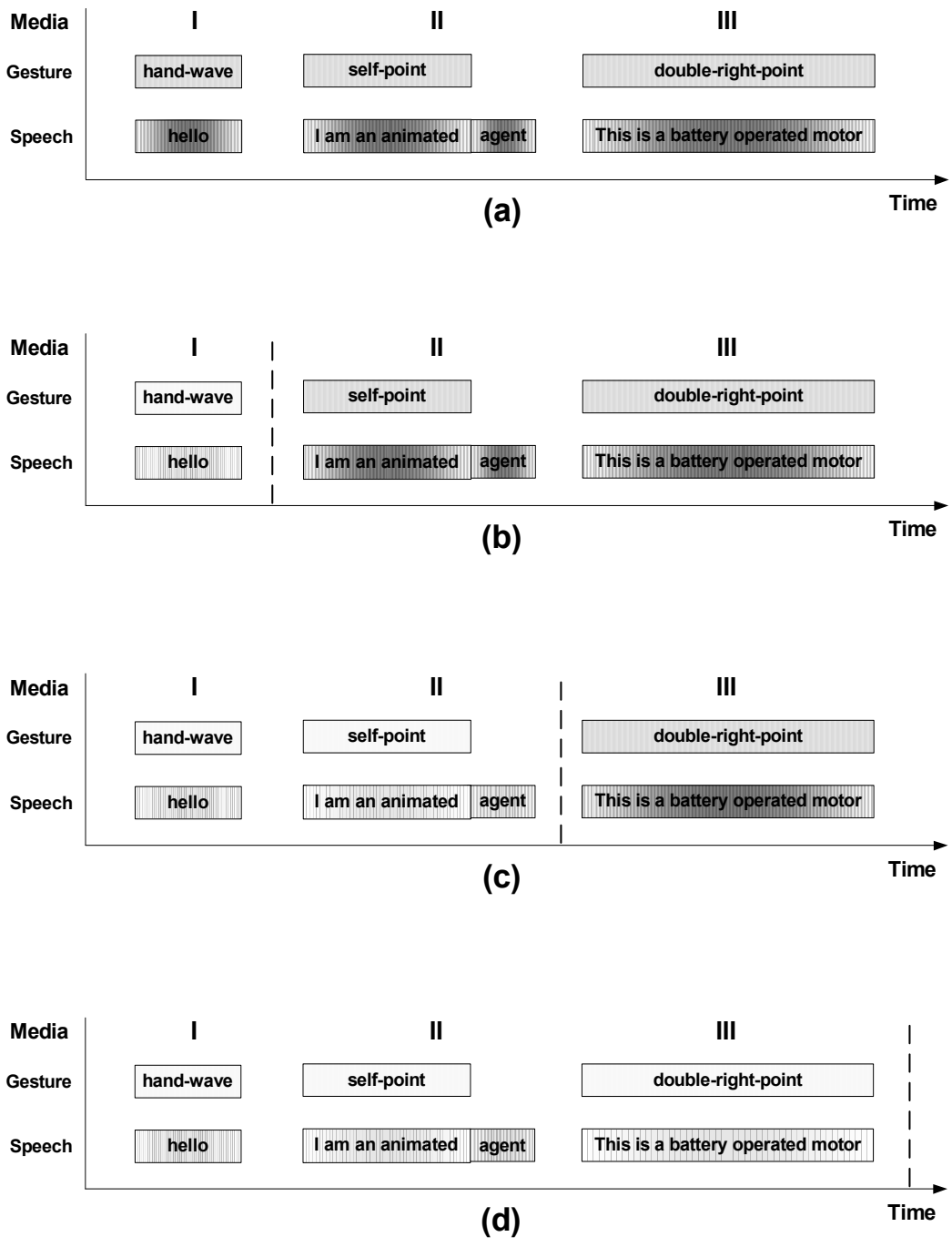


Figure 3-9: Sample Media Element Scheduling

3.5 An IMMPS Based Framework

In order to deliver an effective multimedia presentation, application developers could utilize a generic multimedia synchronization framework to properly synchronize the media elements. Figure 3-10 shows a designed framework for an intelligent multimedia presentation based system.

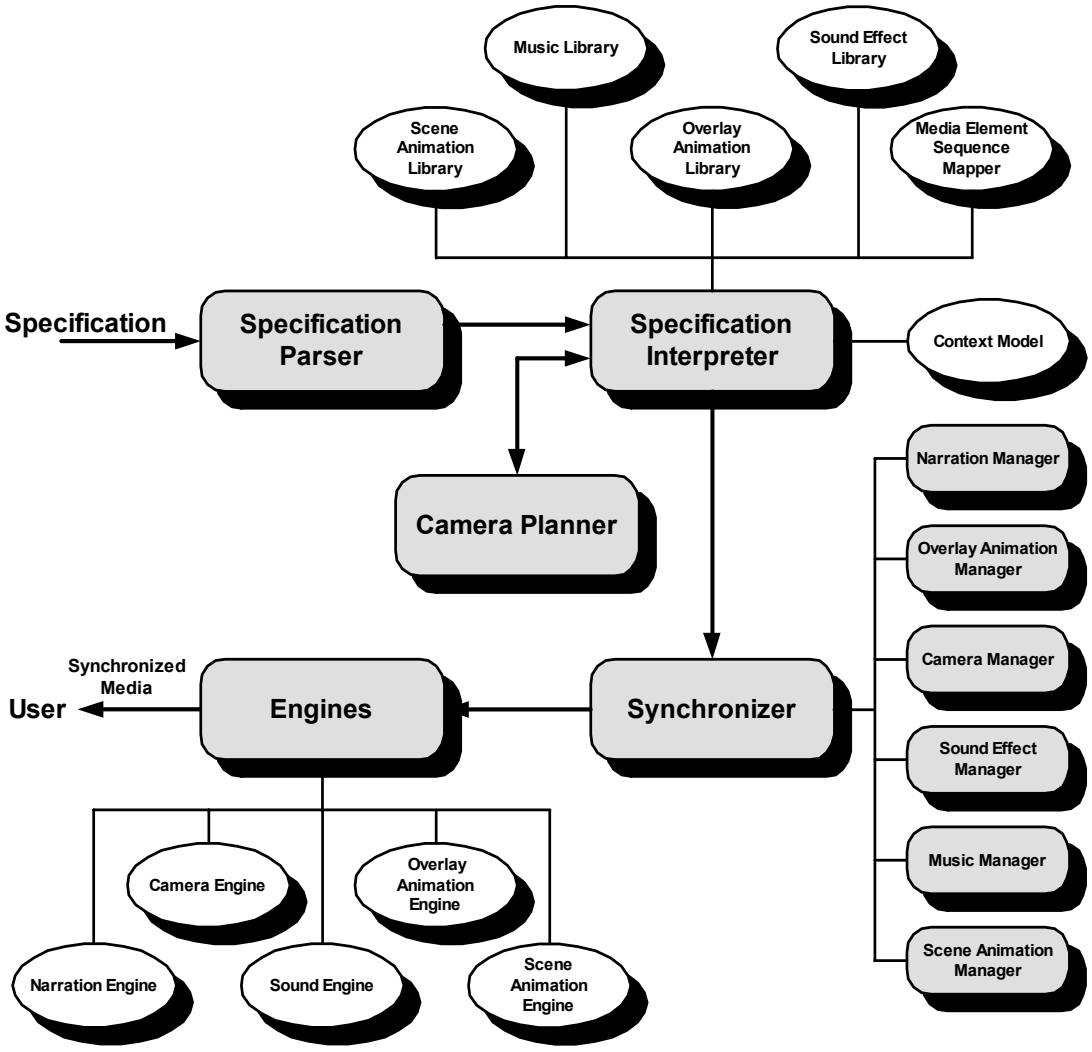


Figure 3-10: A Framework for IMMPS Based Systems

The IMMPS based framework operates in a similar manner as the animated agent based framework. The primary difference between the frameworks is the type of knowledge resources and their corresponding media element managers and engines. The following resources are used primarily in IMMPS synchronization frameworks to make better media elements selection decisions:

- *Scene Animation Library*: Provides animation instructions for each of the world model objects. Each of the animations is pre-scripted and is not created dynamically.
- *Music Library*: Stores information regarding music.
- *Camera Planner*: Plans user viewing goals, based on the current context model, camera position, and the media element's focus object.

By employing these resources, the framework can determine the appropriate media elements for the current multimedia presentation. The selected media elements are then synchronized to achieve the communicative goals between the user and system.

4 An Implemented Animated Agent Based System

The framework for real-time media synchronization has been implemented in PHYSVIZ, a 3D learning environment for the domain of high school physics. An animated agent was incorporated into PHYSVIZ to study the media synchronization framework. The agent utilizes gesture and speech behaviors and presents them in a synchronized manner to provide a real-time interaction with the user. Figure 4-1 shows some examples of gesture media elements for the animated agent in PHYSVIZ.

The framework was implemented in Java and developed as a multithread application. It uses the Java3D, JavaSound, and JavaSpeech APIs to control media elements. The speech synthesis employs the IBM ViaVoice text-to-speech system. The gestures for the agent where created using a motion capture system. FilmBOX, 3D Studio Max, and Character Studio were used for character modeling and blending of motion capture data.

4.1 Specification Language

To represent the proper relationships of media elements, the specification uses an XML-based language. Because of its extensibility, which allows application developers to design their own customized markup languages for different domains, XML is used. The

combination of Java and XML provides interoperability on different platforms. To define a grammar for the specification language, a DTD (Document Type Definition) was created. The DTD defines the syntax rules for the specification language. Figure 4-2 shows the DTD used in PHYSVIZ and a representation of it as a tree structure is shown in Figure 4-3. The '*#PCDATA*' entries in the tree structure denotes text data.

(a) beat

(b) self-point

(c) upper-left point

(d) stretch

(e) hand-wave

Figure 4-1: Example Gestures

```
<?xml version="1.0" encoding="utf-8">
<!DOCTYPE spec [
      <!ELEMENT        spec (focus)+>
      <!ELEMENT        focus (text | gesture | pause | effect)*>
      <!ELEMENT        text (#PCDATA | em | pause | effect)*>
      <!ELEMENT        gesture (#PCDATA | em | effect)*>
      <!ELEMENT        effect EMPTY>
      <!ELEMENT        pause EMPTY>
      <!ELEMENT        em (#PCDATA)>
      <!ATTLIST        focus name CDATA #REQUIRED>
      <!ATTLIST        gesture name CDATA #REQUIRED>
      <!ATTLIST        pause size (large | medium | small) "large">
      <!ATTLIST        effect
         type (sound) "sound"
         name CDATA #REQUIRED
      >
]>
```

Figure 4-2: Document Type Definition for PHYSVIZ Specification

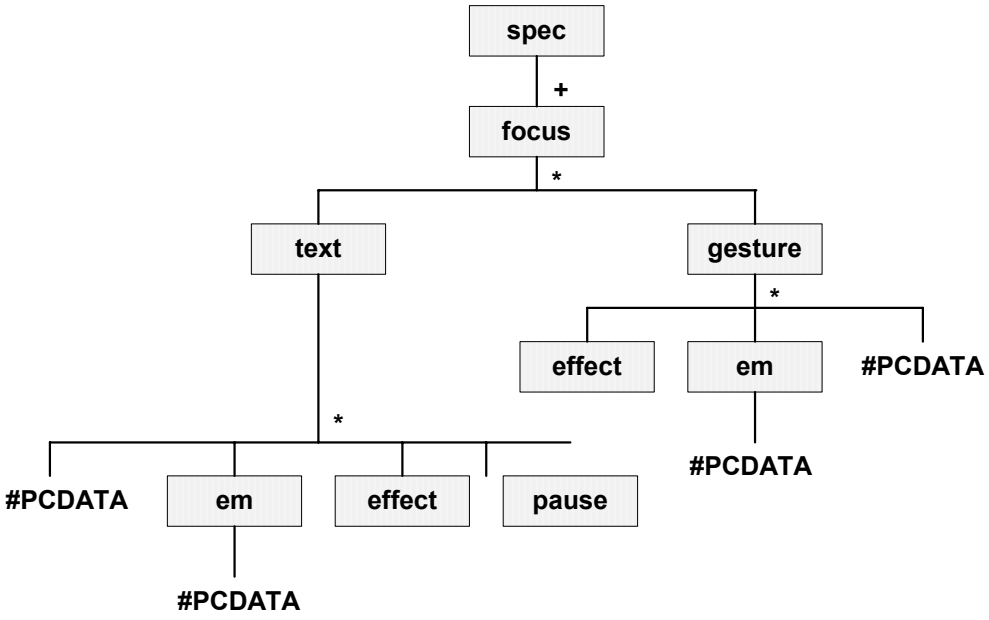


Figure 4-3: Document Type Definition Tree Structure

Using tag elements specified in the DTD, the specification can specify types of media elements and build relationships between media elements. The specification can provide the following information by using tag elements:

- *Focus Object*: The tag element <focus> is used to provide the focus object for its associated media elements by giving the focus name attribute.

- *Agent Speech*: The content of tag element <text> represents spoken text of an agent. To make more realistic speech, sub element and <pause> is used. The tag element is used as emphasizing spoken texts during the agent speech. The tag element <pause> is used to give some interval time of speech pause between spoken texts. The spoken text for the agent can be also represented in a <gesture> tag element.

- *Agent Gesture*: The specification uses tag element <gesture> for the agent gestures. The <gesture> tag element can provide the spoken text data along with the name of the gesture. This action indicates that the presented gesture should start and end with the given text.

- *Special Effect*: The tag element <effect> is used to represent sound effects. If a sound element needs to play by itself without having relations with other media elements, the sound effect tag can be used under a <focus> tag element. The sound effect tag elements can also be used under the <text> and <gesture> tag elements. Each tag element decides when the sound effects can be applied in their context.

The root of all elements is the tag element <spec>, which can define one or more of the <focus> tag elements. The <focus> tag element can specify the <text>, <gesture>, and <effect> tag elements an arbitrary number of times. Each of the tag elements utilizes

attributes to provide additional information about the elements. The attributes of each tag elements are list below.

Tag Element	Attributes	Roles
focus	name	Indicates the name of the focus object.
gesture	name	Indicates name of the agent gesture.
pause	size	Indicates time interval of speech pause. Can specify "large", "medium", and "small" for time interval. Default size is "large".
effect	type	Indicates special effect types. At this point only sound effect is used.
	name	Indicates name of sound effect that needs to play.

4.2 Gesture Element Selection

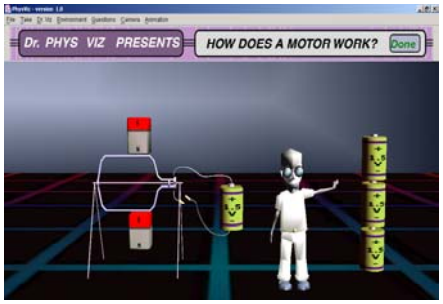
In general, gesture specification is defined at an abstract level. If the agent needs to point to an object, the specification would define its gesture tag element as '*deictic*'. The Specification Interpreter module would select the appropriate pointing gesture for the current context. This way the high-level processing component does not need to figure out the position of the agent and the location of the focus object.

This module uses the Gesture Library, the Context Model, and the Gesture History resources to determine the proper gesture to use. In selecting the pointing gesture, the selection is based on the spatial relation between the current agent position and focus object location. The center of the agent body defines the agent's current position and the center of the focus object identifies its location. The Context Model resource continuously keeps track of these changing agent and model object's locations. The Context Model resource

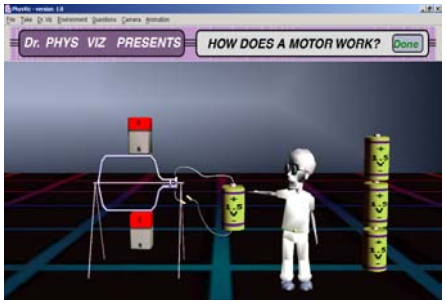
also remembers the agent orientation. This information is used to decide whether or not the agent needs to turn his body to point to the object.

Currently, PHYSVIZ has eight different pointing gestures: *double-left-point*, *up-left-point*, *middle-left-point*, *down-left-point*, *double-right-point*, *up-right-point*, *middle-right-point*, and *down-right-point*. Figure 4-4 illustrates these gestures. If the focus object is on the right side of the agent's current position, the interpreter module retrieves the list of pointing gestures from the Gesture Library and narrows down to the four pointing gestures: *double-right-point*, *up-right-point*, *middle-right-point*, and *down-right-point*. The list is future culled based on the angle between the agent and focus object. If there are multiple choices for selecting a gesture, the interpreter selects the least used gesture by consulting with the Gesture History resource. The following steps show the overall algorithm for selecting the proper gesture:

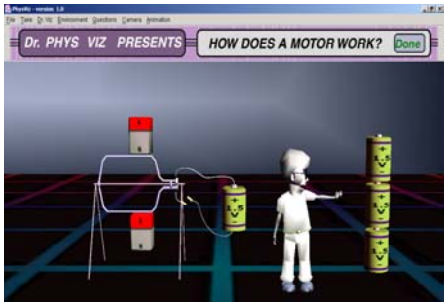
1. Determine the current agent and focus object position
2. Determine orientation of the agent
3. Calculate the vector between the agent position and the focus object
4. Retrieve the list of pointing gestures
5. Find the appropriate gesture using the calculated vector
6. Choose the least used gesture if more than one is available for selection.
7. Turn the agent body towards to the user if necessary.
8. Point at the object.



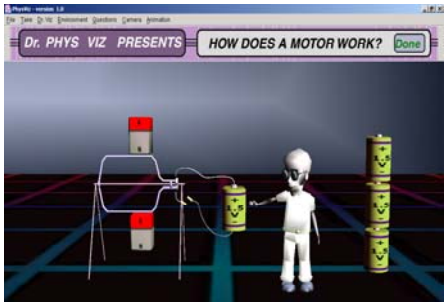
(a) up-left-point



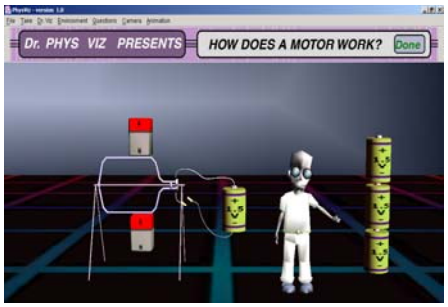
(b) up-right-point



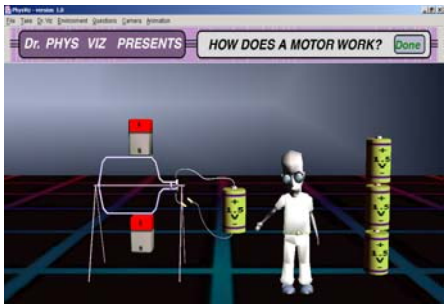
(c) middle-left-point



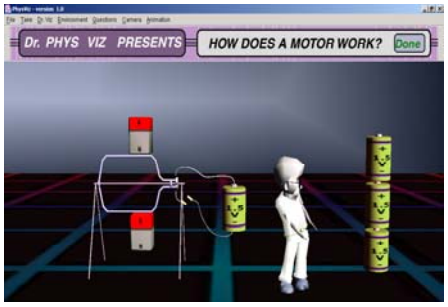
(d) middle-right-point



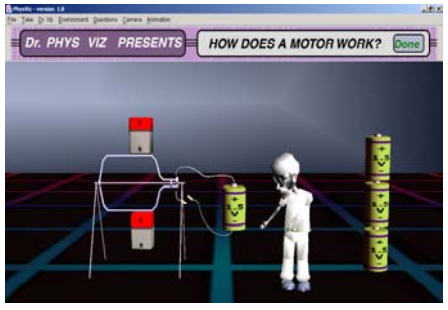
(e) down-left-point



(f) down-right-point



(g) double-left-point



(h) double-right-point

Figure 4-4: Pointing Gestures in PHYSVIZ

4.3 Media Scheduler

The Media Scheduler handles the temporal relations between events specified by the media elements. The media events are notified when each media element starts or completes its execution. The media elements listening to these events can start their execution conditional upon such receiving these notifications. The Media Scheduler in PHYSVIZ can handle *event-based* and *time-based* scheduling. It can also handle a combination of these scheduling mechanisms. In time-based scheduling, media elements specify when they want to be executed by providing time interval information to the scheduler. The Media Scheduler schedules these media element's execution after the given time intervals are passed. Also, the schedulable media elements could ask for both event and time-based scheduling. In event-based scheduling, media elements can be scheduled for their execution conditioned upon the start or end event of a media element, optionally specifying a delay time interval after receiving such an event notification.

Once a listening media element receives an event notification, the scheduler sends this media element to the media trigger queue. The media elements in the media trigger collection wait to satisfy the expiration of their delay time intervals. As soon as their delay time intervals have expired, the scheduler puts them into the corresponding resource waiting queues. Each media element type has its own resource-waiting queue. This permits the scheduler to quickly retrieve a media element as soon as the resource becomes available. Until a media element completes its execution, the resource is marked as busy. Figure 4-5 shows a UML diagram of the media scheduler.

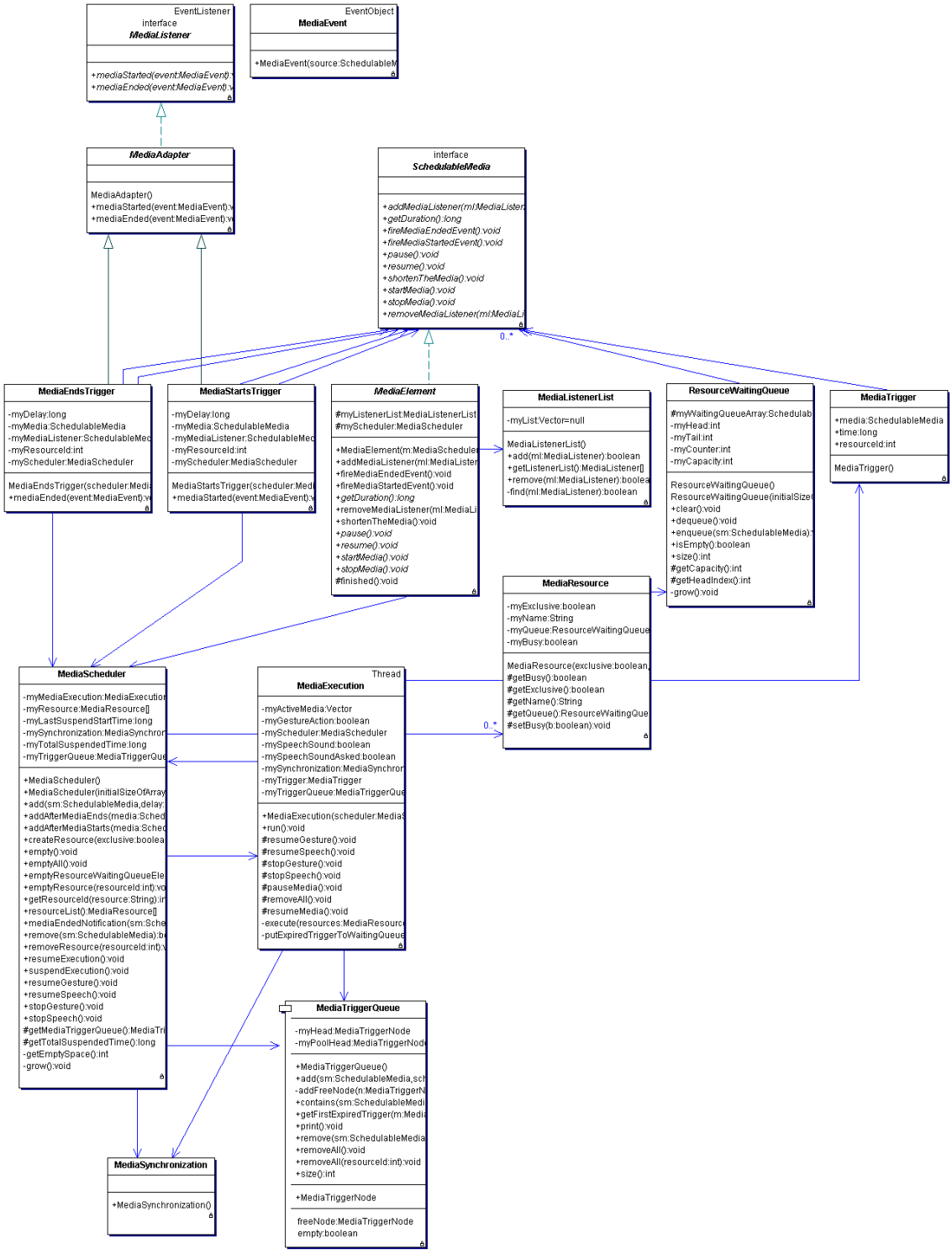


Figure 4-5: UML Diagram of the Media Scheduler

The following is short description of the classes used in the media scheduler:

- *SchedulableMedia*: The Interface that media elements must implement. It provides methods that are necessary for the media scheduler to schedule the implemented media elements. An advantage of having this interface is that the media scheduler can treat all the media elements the same way without knowing the type of media.

- *MediaStartsTrigger*: This class listens for a media element's start event notification. Once a start notification is received it allows dependent media elements to be added to the media scheduler providing delay time interval and its resource type.

- *MediaEndsTrigger*: This class listens for a media element's end event notification. Once an end notification is received, it allows the dependent media element to be added to the media scheduler providing delay time interval and its resource type.

- *ResourceWaitingQueue*: Collection of the media elements that are ready for their media execution. Waiting place until the resource gets free.

- *MediaExecution*: The class that controls the execution of the media elements. It runs as a separate thread.

- *MediaScheduler*: Only accessible class from outside components. The class provides methods to schedule media elements.

4.4 Animation

The gesture animation was created using the FilmBOX motion capture system. The motion-captured data was filtered and blended using FilmBOX and Character Studio. Once the motion-captured animation was cleaned up, that data was exported as a BioVision Hierarchy (BVH) file. The resulting BVH file holds the edited character movement

information generated from the motion capture system. It contains information about the character's joint hierarchy, such as translation, rotation, and scale that are relative to the parent joint. It also contains information about motion-captured data, which is presented as numeric values in a series of frames. A sample BVH file showing the first 5 frame of motion capture data is shown in Figure 4-6.

```
HIERARCHY
ROOT Hips
{
  OFFSET 0.0 0.0 0.0
  CHANNELS 6 Xposition Yposition Zposition Zrotation
             Xrotation Yrotation
  JOINT LeftHip
  {
    OFFSET 3.43 0.0 0.0
    CHANNELS 3 Zrotation Xrotation Yrotation
    JOINT LeftKnee
    {
      OFFSET 0.0 -18.47 0.0
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT LeftAnkle
      {
        OFFSET 0.0 -17.95 0.0
        CHANNELS 3 Zrotation Xrotation Yrotation
        End Site
        {
          OFFSET 0.0 -3.12 0.0
        }
      }
    }
  }
  JOINT RightHip
  {
    OFFSET -3.43 0.0 0.0
    CHANNELS 3 Zrotation Xrotation Yrotation
    JOINT RightKnee
    {
      OFFSET 0.0 -18.47 0.0
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT RightAnkle
      {
        OFFSET 0.0 -17.95 0.0
        CHANNELS 3 Zrotation Xrotation Yrotation
        End Site
        {
          OFFSET 0.0 -3.12 0.0
        }
      }
    }
  }
  JOINT Chest
  {
    OFFSET 0.0 4.57 0.0
    CHANNELS 3 Zrotation Xrotation Yrotation
    JOINT LeftCollar
    {
      OFFSET 1.06 15.33 1.76
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT LeftShoulder
      {
        OFFSET 5.81 0.0 0.0
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT LeftElbow
        {
          OFFSET 0.0 -12.08 0.0
          CHANNELS 3 Zrotation Xrotation Yrotation
          JOINT LeftWrist
          {
            OFFSET 0.0 -9.82 0.0
            CHANNELS 3 Zrotation Xrotation Yrotation
            End Site
            {
              OFFSET 0.0 -7.37 0.0
            }
          }
        }
      }
    }
    JOINT RightCollar
    {
      OFFSET -1.06 15.33 1.76
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT RightShoulder
      {
        OFFSET -5.81 0.0 0.0
        CHANNELS 3 Zrotation Xrotation Yrotation
        JOINT RightElbow
        {
          OFFSET 0.0 -12.08 0.0
          CHANNELS 3 Zrotation Xrotation Yrotation
          JOINT RightWrist
          {
            OFFSET 0.0 -9.82 0.0
            CHANNELS 3 Zrotation Xrotation Yrotation
            End Site
            {
              OFFSET 0.0 -7.37 0.0
            }
          }
        }
      }
    }
    JOINT Neck
    {
      OFFSET 0.0 17.62 0.0
      CHANNELS 3 Zrotation Xrotation Yrotation
      JOINT Head
      {
        OFFSET 0.0 5.19 0.0
        CHANNELS 3 Zrotation Xrotation Yrotation
        End Site
        {
          OFFSET 0.0 4.14 0.0
        }
      }
    }
  }
}
MOTION
Frames: 129
Frame Time: 0.033333
0.00 0.00 0.00 0.00 0.00 -0.00 -2.31 11.24 0.80 0.13 -2.52
-0.07 2.06 -8.32 -0.39 2.23 10.70 -0.76 -0.13 -2.52 0.07
-1.99 -7.78 0.38 -0.00 -5.58 -0.00 -21.23 2.53 -4.09 26.17
0.15 -39.68 0.21 -11.18 0.29 -0.90 11.97 20.78 21.65 2.02
2.92 -29.85 0.97 38.95 -0.21 -11.19 -0.29 0.88 11.97
-20.70 -0.00 -0.17 -0.00 -1.20 4.86 0.37

0.00 0.00 0.00 0.00 0.00 -0.00 -2.31 11.24 0.80 0.13 -2.52
-0.07 2.06 -8.32 -0.39 2.23 10.70 -0.76 -0.13 -2.52 0.07
-1.99 -7.78 0.38 -0.00 -5.58 -0.00 -21.23 2.53 -4.09 26.17
0.15 -39.68 0.21 -11.18 0.29 -0.90 11.97 20.78 21.65 2.02
2.92 -29.85 0.97 38.95 -0.21 -11.19 -0.29 0.88 11.97
-20.70 -0.00 -0.17 -0.00 -1.23 4.85 0.40

0.00 0.00 0.00 0.00 0.00 -0.00 -2.31 11.24 0.80 0.13 -2.52
-0.07 2.06 -8.32 -0.39 2.23 10.70 -0.76 -0.13 -2.52 0.07
-1.99 -7.78 0.38 -0.00 -5.58 -0.00 -21.23 2.53 -4.09 26.17
0.15 -39.68 0.21 -11.18 0.29 -0.90 11.97 20.78 21.65 2.02
2.92 -29.85 0.97 38.95 -0.21 -11.19 -0.29 0.88 11.97
-20.70 -0.00 -0.17 -0.00 -1.32 4.84 0.50

0.00 0.00 0.00 0.00 0.00 -0.00 -2.31 11.24 0.80 0.13 -2.52
-0.07 2.06 -8.32 -0.39 2.23 10.70 -0.76 -0.13 -2.52 0.07
-1.99 -7.78 0.38 -0.00 -5.58 -0.00 -21.23 2.53 -4.09 26.17
0.15 -39.68 0.21 -11.18 0.29 -0.90 11.97 20.78 21.65 2.02
2.92 -29.85 0.97 38.95 -0.21 -11.19 -0.29 0.88 11.97
-20.70 -0.00 -0.17 -0.00 -1.45 4.83 0.65

0.00 0.00 0.00 0.00 0.00 -0.00 -2.31 11.24 0.80 0.13 -2.52
-0.07 2.06 -8.32 -0.39 2.23 10.70 -0.76 -0.13 -2.52 0.07
-1.99 -7.78 0.38 -0.00 -5.58 -0.00 -21.23 2.53 -4.09 26.17
0.15 -39.68 0.21 -11.18 0.29 -0.90 11.97 20.78 21.65 2.02
2.92 -29.85 0.97 38.95 -0.21 -11.19 -0.29 0.88 11.97
-20.70 -0.00 -0.17 -0.00 -1.63 4.81 0.85
```

Figure 4-6: Sample BVH Animation File

To incorporate the BVH file data into the PHYSVIZ environment, a BVH interpreter was developed to apply the motion captured character movements to the animated agent. The BVH interpreter provides character movement information used by the Java3D API control the articulated character motion in real-time.

The system attempts to keep the frame rate running at 30 fps at all times. It continuously monitors the frame rates and if it falls below the given rate, it uses frame-skipping techniques to keep the animations running at the correct speed. The frame-skipping technique is also used to achieve synchronization. If a gesture element's duration is longer than the associated speech element and they need to start and finish together, the graphic engine skips frame to reduce the execution duration.

A simple word-level lip-synching animation technique is also implemented in the system. The animated agent moves his jaw with every word of spoken text. The speed of jaw movement is determined by the speech rate: if the speech rate is fast, the movement of the agent's jaw is quicker.

4.5 Examples

To illustrate how the framework operates for the animated agent in PHYSVIZ, three examples are presented below. Each example attempts to select the most appropriate gestures for current context. In the first example, all of the media elements are well-defined. The specification did not give any abstract level of information. There is an abstraction of the gesture element in the second example. Finally, the third example shows that two completely different focus objects can be specified in a single specification.

4.5.1 “Hello! I am an animated agent.”

There are two separate speech elements in this example. Each of them has an associated gesture element. The text elements are “Hello!” and “I am an animated agent”. The corresponding gestures are “hand-wave” and “self-point”, respectively. The specification for this example is shown below:

```
<spec>
        <focus name="">
                <gesture name=”hand-wave”>”Hello!”</gesture>
                <pause size=”small”/>
                <gesture name=”self-point”>
                        “I am an animated agent”
                </gesture>
        </focus>
</spec>
```

Based on the specification, the “hand-wave” and “self-point” gestures should start and end with their speech element. The Specification Parser parses the specification and sends information to the Specification Interpreter. Since the exact gesture name is defined, the interpreter retrieves the corresponding media element instruction data from the Gesture Library resource. The interpreter also calculates the duration of each speech elements and sends this information to the synchronization module. This execution time duration is helpful to determine the gesture animation time frame. In the Synchronization module, the media events are created for their proper synchronization and scheduling. In this example, the speech element “Hello!” fires a start event notification as soon as the speech is started. The gesture element “hand-wave” was listening for the event and starts its media execution. The next pair of speech and gesture works the same way. After a brief speech pause, the

second speech element sends a start event notification and the gesture element starts its animation. The graphical version of the example is given in Figure 4-7.

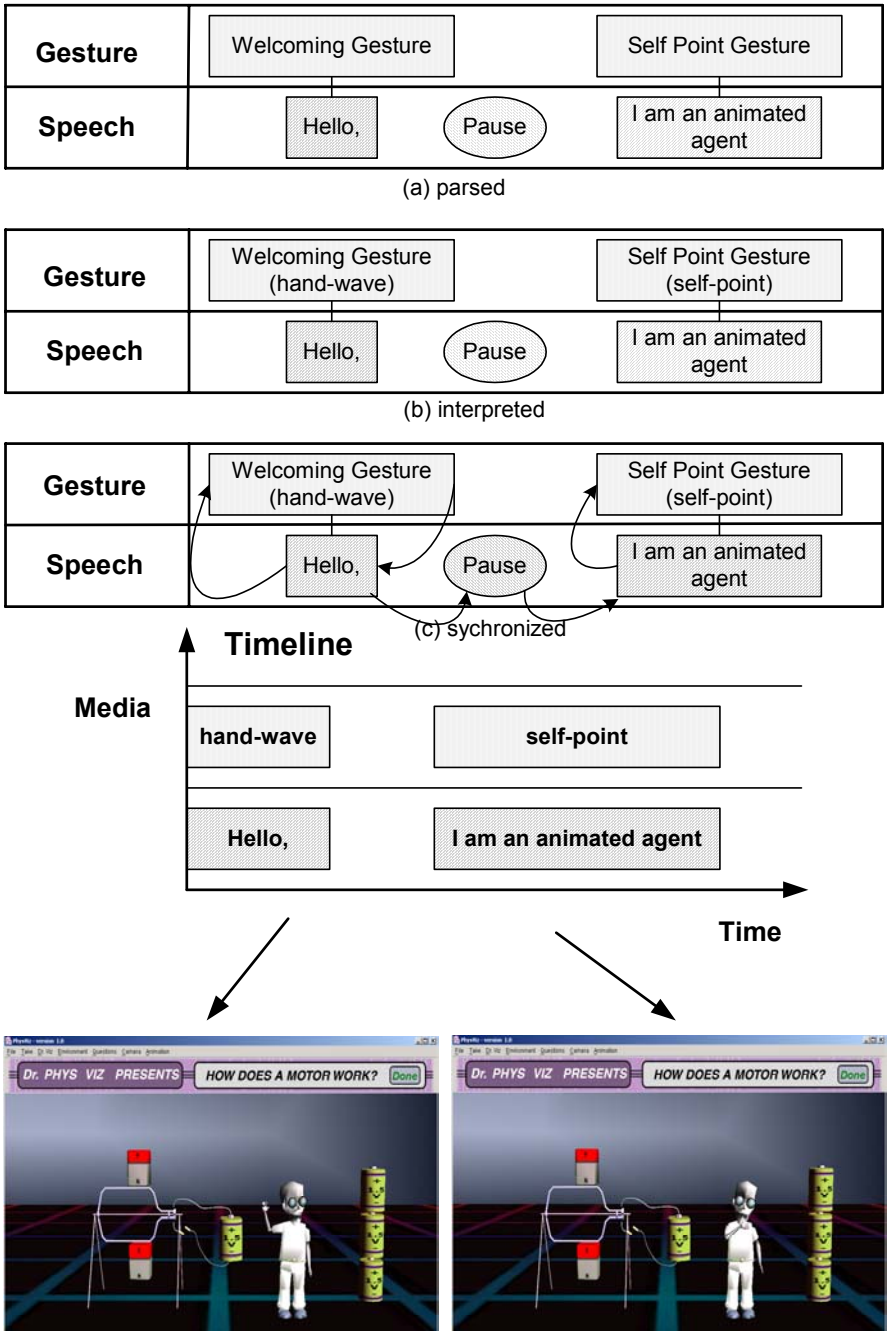


Figure 4-7: "Hello! I am an animated agent."

4.5.2 "I want to introduce you to a very interesting piece of equipment."

In this example, there is an abstract gesture element is specified. The gesture element "beat" is specified along with a speech element. The specification is shown below:

```
<spec>
        <focus name="">
                <gesture name="beat">
                        "I want to introduce you to a very interesting
                         piece of equipment."
                </gesture>
        </focus>
</spec>
```

The interpreter decides which beat gesture is appropriate to use. First, the interpreter retrieves the beat gesture list from the Gesture Library. Each of the gestures in the list is compared with the Gesture History to find out its selection count. The gesture with the lowest selection count is selected. The selected gesture element is sent to the Synchronizer along with its speech element. By providing the start media event on the speech element and media execution time duration, the speech element and gesture element starts and ends together. Figure 4-8 shows step-by-step diagram of the procedure.

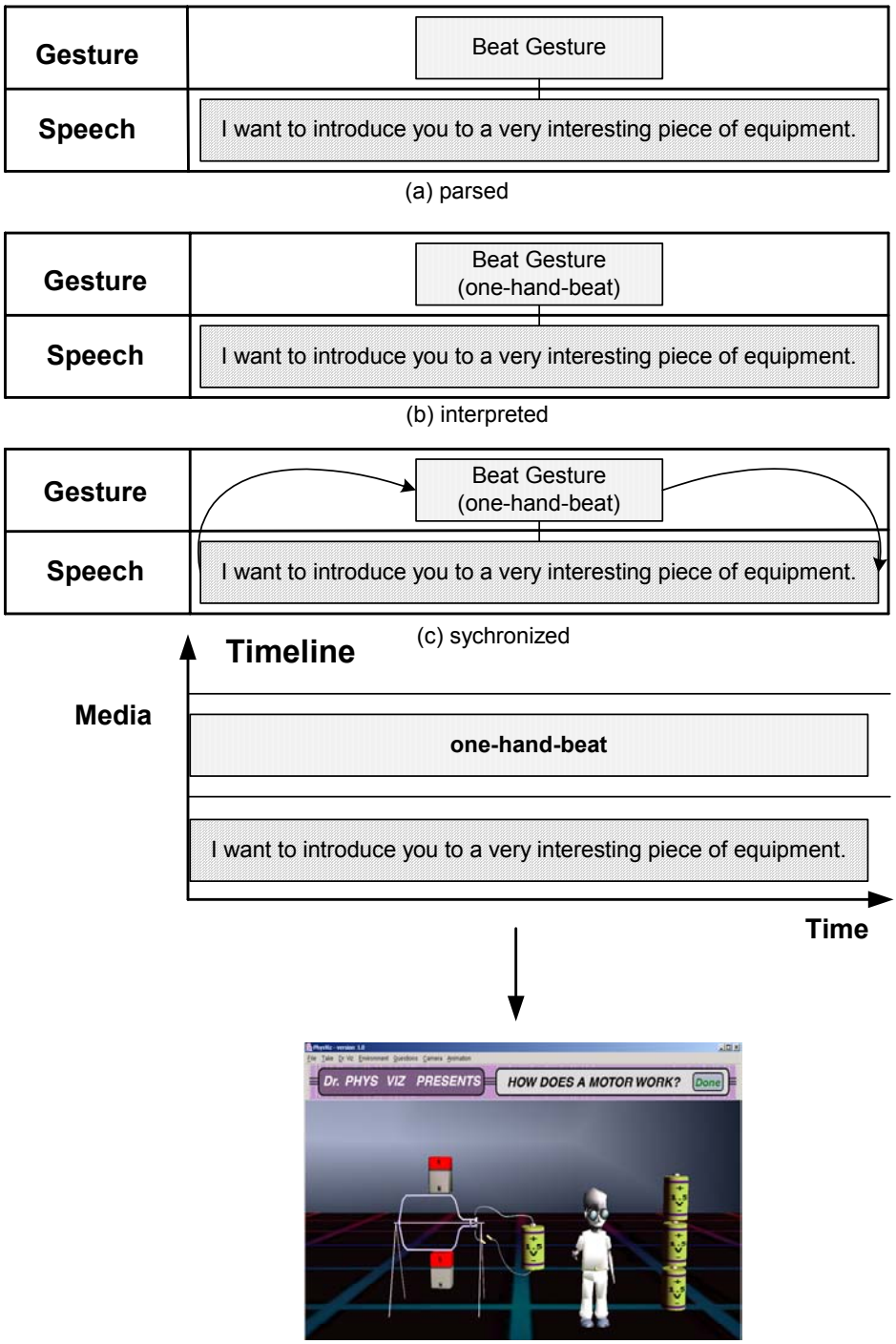


Figure 4-8: "I want to introduce you to a…"

4.5.3 "This is a battery operated motor and …"

As shown below, the specification defines two focus objects in a single specification. Each focus object is used to determine the appropriate gestures for the current context.

```
<spec>
        <focus name="motor">
                <gesture name="deictic">
                        "This is a battery operated motor."
                </gesture>
                <pause size="large"/>
                <text>and</text>
        </focus>
        <focus name="extra-battery">
                <gesture name="deictic">
                        "These are <em>extra</em> batteries"
                </gesture>
        </focus>
</spec>
```

By determining the current agent and focus object position, the interpreter can compute the vector between the center of the agent's body and the model object. Using the calculated vector, the interpreter can select the appropriate gesture element that conforms to the current context. The "back-right-point" and "middle-left-point" gestures are selected for the first and second gesture elements, respectively as shown in Figure 4-9.

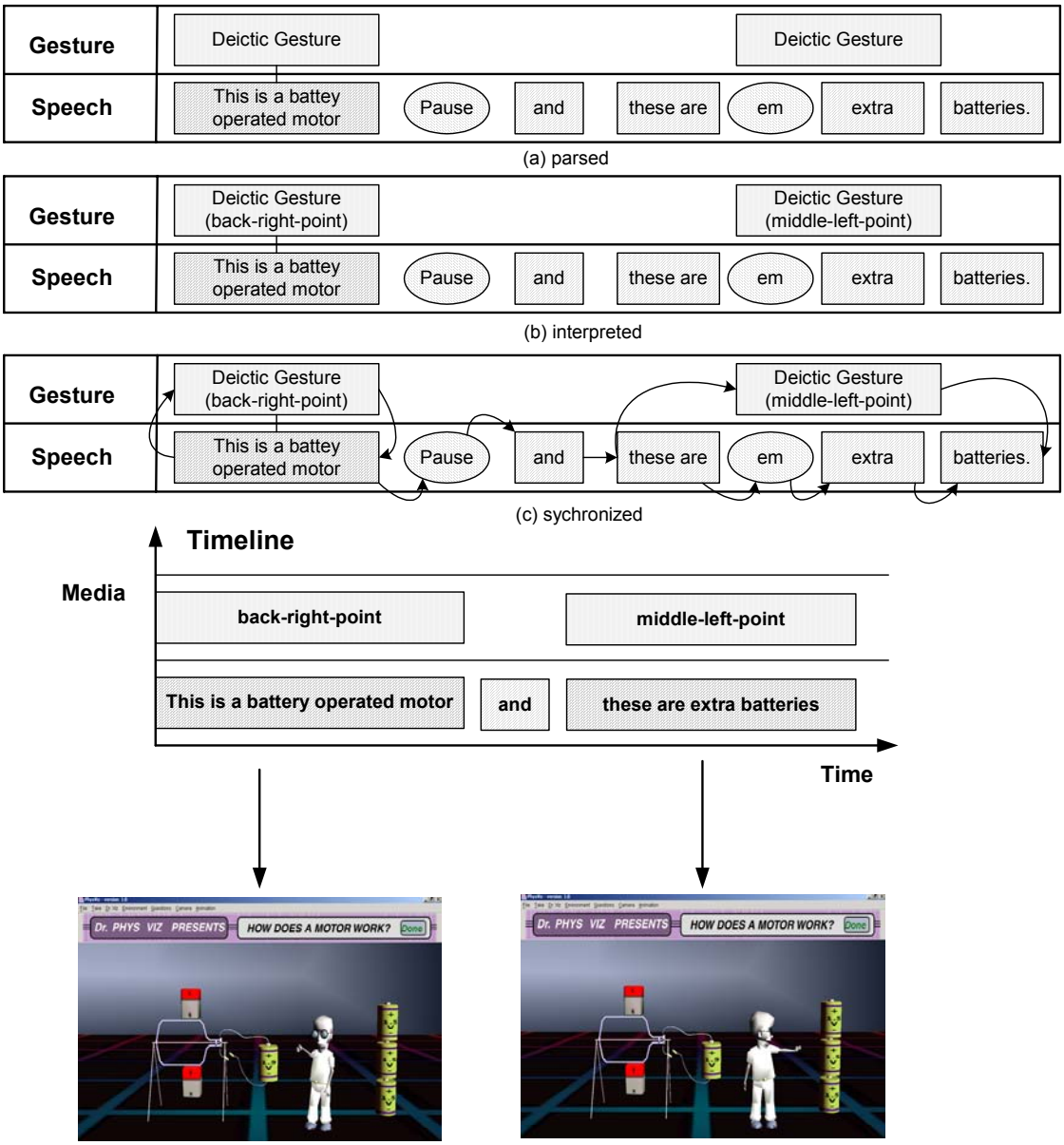


Figure 4-9: "This is a battery operated motor and…"

5 Related Work

A large literature has emerged on animated agents and intelligent multimedia presentation systems. This chapter reviews key work in these areas and discusses how the framework relates to it.

REA is an embodied conversational agent, which interacts with the user as a real estate agent (Cassell *et al*., 1999). She generates nonverbal behaviors along with verbal behaviors to provide richness in face-to-face conversation with users such as raising eyebrow for emphasis, eye gaze and head nods for turn taking behaviors, and gestures. The system formulates behavior sequences to carry out the desired communicative goals based on the input from a microphone and camera. The Action Scheduler module is responsible for synchronizing these behaviors and attempts to carry them out. This module could be replaced with the proposed framework or implemented based on the framework.

KARE is a conversational animated agent integrated with a bilingual-capable talking-head system (King *et al*., 2003). TE KAITITO, the dialog system for KARE, supports two different languages to converse with users, English and Māori. KARE can also support culture-specific dialog and nonverbal behaviors. The Id module generates nonverbal behaviors and provides personality to KARE such as eye gazing, blinking, and furrowing the brows. These generated nonverbal behaviors are culture-specific which means it does not only depended on the dialog but it also depended on the language used. The generated

verbal and nonverbal behaviors are sent to the TalkingHead module to synchronize these behaviors. In this module, the proposed framework could be effectively utilized.

FLURMAX is a virtual animated agent, which inhabits a wide-screen panel with a camera attached to get a visual perception of the environment (Jung *et al*., 2003). FLURMAX interacts with a person who passing by or standing in front of the panel by using speech, gesture, and facial expressions. The visual perception component processes the video data and sends events to the central component to create and schedule behavior routines. The execution component receives these behavior routines and executes them. The central component generates MURML (Multimodal Utterance Representation Markup Language) as behavior specification, which is an XML-based language to specify prosodic speech, gestures, emotional expression, and locomotion. The proposed framework could be used in the behavior execution component without affecting the overall system architecture and the specification language used in FLURMAX.

The framework can also be utilized in other applications that utilize embedded animated agent. For example, a conversational animated agent is used as a sales assistant in the virtual market place (Guerin *et al*., 2001). An agent communicates with users by using speech and gestures to enhance believability as a sales assistant. The Action Planner module in the system plans and generates behavioral actions. The actions are formalized in CML (Character Markup Language) to describe body movements, speech output, and emotional parameters. CML is an XML-based scripting language. These character actions are sent to the lower-level processes to synchronize gestures and verbal communications.

The system could implement the low-level processes using the proposed framework without changing CML.

Another example is the STORYTELLER (Silva *et al*., 2001). The STORYTELLER is an animated agent, which inhibits a 3D virtual world and narrates a story with proper emotional expressions as the story progresses. The system uses tags within a text to control the emotional state of the character and its gestures. The proposed framework can be applied to their lower-level process to provide the proper synchronization between the verbal and nonverbal behaviors based on the annotated specification text produced by the system.

Also, the framework can be applied in Intelligent Multimedia Presentation Systems as well. PPP system (André and Rist, 1996) generates intelligible presentations that instruct the user. To achieve complex presentation goals, the system generates the presentation strategy scripts dynamically and assembles the multimedia sets to be presented to the user in real-time. PPP also exploits Allen's temporal relations to satisfy the temporal constraints between the presentation acts. The proposed framework could provide a solution to the lower-level processes for carrying out the generated complex multimedia presentation plans.

ROBOCUP simulation league commentator systems (André *et al*., 2000) are systems that could utilize the framework. Rocco, MIKE, and Byrne are commentary systems in the soccer domain. They generates appropriate spoken commentary in real-time. Rocco (Voelz *et al*., 1998) generates TV-style live reports for soccer simulation league with two-dimensional graphic simulations. Byrne (Binsted, 1998) generates the appropriate speech

and facial expressions based on the state of the game. Byrne creates SEEML (the Speech, Expression and Emotion Mark-up Language) to tag emotional state within a text. As a result, Byrne provides emotional and expressive talking-head commentary. Mike, the Multi-agent Interactions Knowledgeably Explained, (Tanaka *et al*., 1998) is a system that produces simultaneous spoken commentary. Output is generated in real-time either in English, Japanese, or French.

IMPROVISE, the Illustrative Metaphor PROduction in VISual Environement, (Zhou and Feiner, 1998) is a knowledge-based system that can automatically generate coherent visual presentations. To properly design visual illustrations, the IMPROVISE employs the PAL (Presentation Authoring Language). PAL can represent visual objects and visual techniques as the nodes. The specifications of temporal constraints between visual objects and techniques are encapsulated in the nodes. The proposed framework can be used as their lower-level process to properly perform the medias specified in specifications.

PMO is a multimodal presentation planner in the EMBASSI project (Elting and Michelitsch, 2001). EMBASSI is an intelligent user interface trying to simplify the use of everyday life technology thru proper management of intelligent multimodal interaction. The system supports speech, an animated life-like character, and a GUI as output modalities. PMO plans which modalities are used as output and how these modalities should work with each other. The framework could produce these planned output modalities with proper synchronization to the user.

The current framework supports only temporal based presentations systems. It would not be appropriate for a spatial presentation system such as AUTOBRIEF (Kerpedijiev *et al*., 1997) and PERSIVAL (McKeown, 2001).

Properly handling multimedia synchronization issues are also important in the areas of transmitting multimedia information over a network. SMIL, Synchronized Multimedia Integration Language, (SMIL, 2001) is used to describe multimedia presentations for web-based multimodal applications. The video and audio streaming area receives significant attention in media synchronization (Herman, 1998; Zhou and Murata, 2001). However, the proposed framework may be more complex process since it handles significantly more modalities for proper synchronization.

6 Conclusions and Future Work

The management of real-time multimedia synchronization is a critical issue in multimodal environments because the overall effectiveness of the system is significantly reduced if it is mismanaged. Most media-rich systems have solved some aspects of the media element synchronization and scheduling problem. However, they have done so in an *ad hoc* manner without providing a generic reusable framework. One approach for achievingproper media element synchronization in real-time is to partition the synchronization and scheduling into high-level and lower-level processing components communicating via a well-defined media element specification. Prior research efforts have produced specification languages such as VHML (Beard and Reid, 2002), MPML (Ishizuka *et al*., 2000), CML (Guerin *et al*., 2001), and SEEML (Binsted, 1998). However, their work has focused on the languages and not the details of the synchronization issues.

To this end, we have designed and implemented a generic framework that can support low-level media synchronization. In the course of designing and implementing the framework, several benefits emerged. They can be summarized as follows:

- *Intuitiveness*: By using a specification language and properly defining its syntax, the presentations of media elements can be unambiguously defined and executed.

- *Extensibility*: Because the framework supports the addition of new modalities without affecting existing media element components, new knowledge resources and components can be created with ease. Furthermore, modules in the framework can be easily modified without affecting others. For example, the Specification Interpreter can be modified easily when new media element selection strategies are needed.

- *Applicability*: The implemented framework can be easily combined with high-level processing components without any modifications because it clearly defines its operations and operates as a separate entity from the high-level processing component.

- *Ease of development*: Because the high-level and low-level processing components are properly decoupled, application developers can focus on their own task without concern for how their changes might affect each other tasks.

To demonstrate the practicality of the framework, it was implemented in PHYSVIZ, an interactive 3D learning environment for the domain of high school physics. This system illustrates how using the framework can support the separation of high-level and low-level media element processing components. In the implementation, these high-level and low-level components communicated via a media element specification language and achieved the proper media element synchronization in real-time.

6.1 Future Work

Several areas of additional work have been uncovered resulting the course of developing the framework:

- *Extend temporal constraints*: By manipulating the order of media element events and time delays, the framework can provide media synchronization. However, the present framework's media element temporal relations are not fully expressive. Certainly much more remains to be done. Based on Allen's temporal reasoning model (Allen, 1983), the current framework can only handle the *equal*, *after*, *starts*, and *started_by* temporal relations. By providing more temporal relations, the framework could achieve a fine-granularity of media synchronization.

- *Improve specification language*: There are numerous media elements that must be controlled in a complex media environment such as lighting effects, movements of objects, changing colors, camera motion, sound effects, character facial expressions, character movements, and speech. The specification language should be expressive enough to specify all of these media elements for simultaneous presentation. Therefore, developing an expressive specification language is necessary to handle complex media environments.

- *Improve animation scaling*: The current framework implementation uses a frame-skipping technique to match the duration of an animation to the accompanying speech. This mechanism presents a problem when considerably different time duration exists between the gesture and speech. A more intelligent mechanism to properly handle this is needed.

- *Define levels of abstraction*: Determining well-defined levels of abstraction for media elements is important. The presentation of media elements may not be expressive enough if the level of abstraction is too high. If it is too low, the high-level processing component have to perform additional processing to determine the detailed media element selection.

- *Obtain dynamically creating media element duration*: Recognizing the execution time duration of a media element is an essential part of media synchronization.

Since the duration is used to provide an appropriate animation to match associated media elements. If the duration of a media element is unknown because it is created dynamically, the resulting media presentation would not be synchronized. A mechanism to obtain the duration of a dynamically generating media element would be beneficial to the framework.

- *Integrate with multimedia network system*: The framework should be aware of the "channel" for which the media presentation is being generated. For example, if the presentation is being displayed on a small handheld device, the framework should reason about the target device and determine how the media elements should be displayed.

6.2 Concluding Remarks

A framework for real-time synchronization in media-rich systems offers significant potential for improving the quality of media presentations by achieving proper synchronization and scheduling of media elements. This type of framework can be utilized in a wide variety of interactive systems, including virtual reality training, education, simulation, and entertainment applications. As multimedia technology advances, more complex media systems will be created. The proposed framework offers a solid foundation for the design and implementation of media synchronization technique for these applications.

7 References

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