Visual Planning: A Practical Approach to Automated Presentation Design

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Abstract^

Based on a set of design principles, automated visual presentation systems promise to simplify an application programmer's design tasks by automatically constructing appropriate visual explanations for different information. However, these automated presentation systems must be equipped with a powerful inference approach to suit practical applications. Here, we present a planning-based, practical inference approach that can design a series of connected visual presentations in interactive environments. Our emphasis here is on a set of important visual planning features and how they facilitate visual design. This set of features includes a knowledge-rich representation of visual planning variables and constraints, a novel object-decomposition model that can be used with action decomposition to simplify the visual synthesis process, and practical temporal and spatial reasoning capabilities to facilitate coherent visual design and presentation. In addition, we have implemented our visual planning approach in a visual planner called PREVISE, as part of our automated presentation testbed system. A set of examples is also given to illustrate the necessity and utility of our visual planning approach.

1 Introduction

Automated visual presentation systems rely on a powerful inference engine to generate desired presentations efficiently. In this paper, we present a practical inference method that uses a planning approach to infer visual designs in interactive environments.

A visual design ultimately appears in the form of a *visual discourse* that consists of sequences of temporally ordered visual actions [Zhou, 1998]. Visual actions are encoded visual techniques, which may render a collection of graphics objects on the screen (e.g., action Display), or animate a graphical transformation (e.g., Enlarge). Since such a pattern is reminiscent of the result produced by AI planning, we model visual design as a planning problem. In particular, the communicative goals are accomplished as planning goals, visual design guidelines are maintained as planning constraints, and visual actions are employed as planning operators to construct a visual plan (a visual discourse).

The core of our visual planning is a least-commitment, top-down hierarchical decomposition partial-order planning approach [Young et al., 1994]. Combined with a set of visual design heuristics [Zhou and Feiner, 1997], this approach helps minimize costly redesign, eases knowledge encoding by reusing visual actions, and ensures global and local design coherency. Furthermore, we have equipped the core approach with an additional set of features. Specifically, we provide a versatile visual planning representation formalism to express and manage progressively refined visual plans. To simplify visual object synthesis and knowledge management, we explicitly address object decomposition. We also augment visual planning with temporal and spatial reasoning capabilities to maintain temporal and spatial constraints [Allen, 1983; Freeman-Benson, 1993]. In addition, we have implemented our approach in a visual planner called PREVISE (Planning in REactive VISual Environments), which is part of an automated presentation testbed system.

In the rest of the paper, we focus on illustrating these important features of our visual planning approach. But first we briefly describe several related works, followed by an example that is planned by PREVISE to illustrate the visual planning problem. We then describe four important visual planning features and explain how they facilitate automated visual design. Finally, we present our conclusions and indicate some future research directions in visual planning.

2 Related Work

While most automated presentation systems employ simple search-based approaches (e.g., [Seligmann and Feiner, 1991]), a few have used planning approaches (e.g., [Andre and Rist, 1993; Karp and Feiner, 1993; Bares and Lester, 1997]). However, systems using planning approaches either deal with static presentations I Andre and Rist, 1993] or focus on planning camera movements [Karp and Feiner, 1993; Bares and Lester, 1997]. Furthermore, these systems usually handle premade graphics objects at a high level without worrying about low-level visual object composition (e.g., composing a visual object using basic visual ele-

t This work was conducted at Columbia University, as part of the author's Ph.D. thesis in the Dept. of Computer Science.

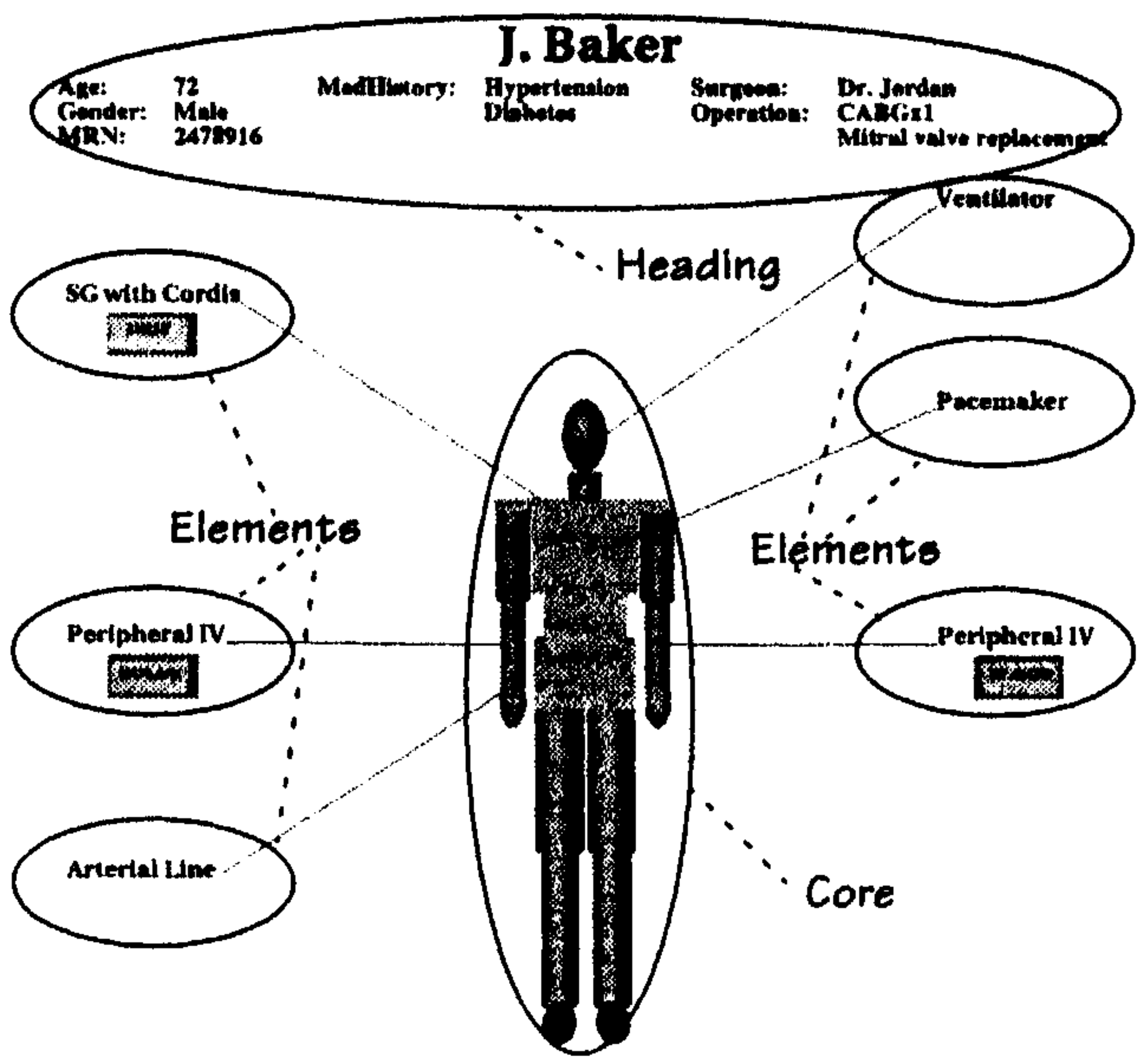


Figure 1. Present patient overview to nurse (annotated)

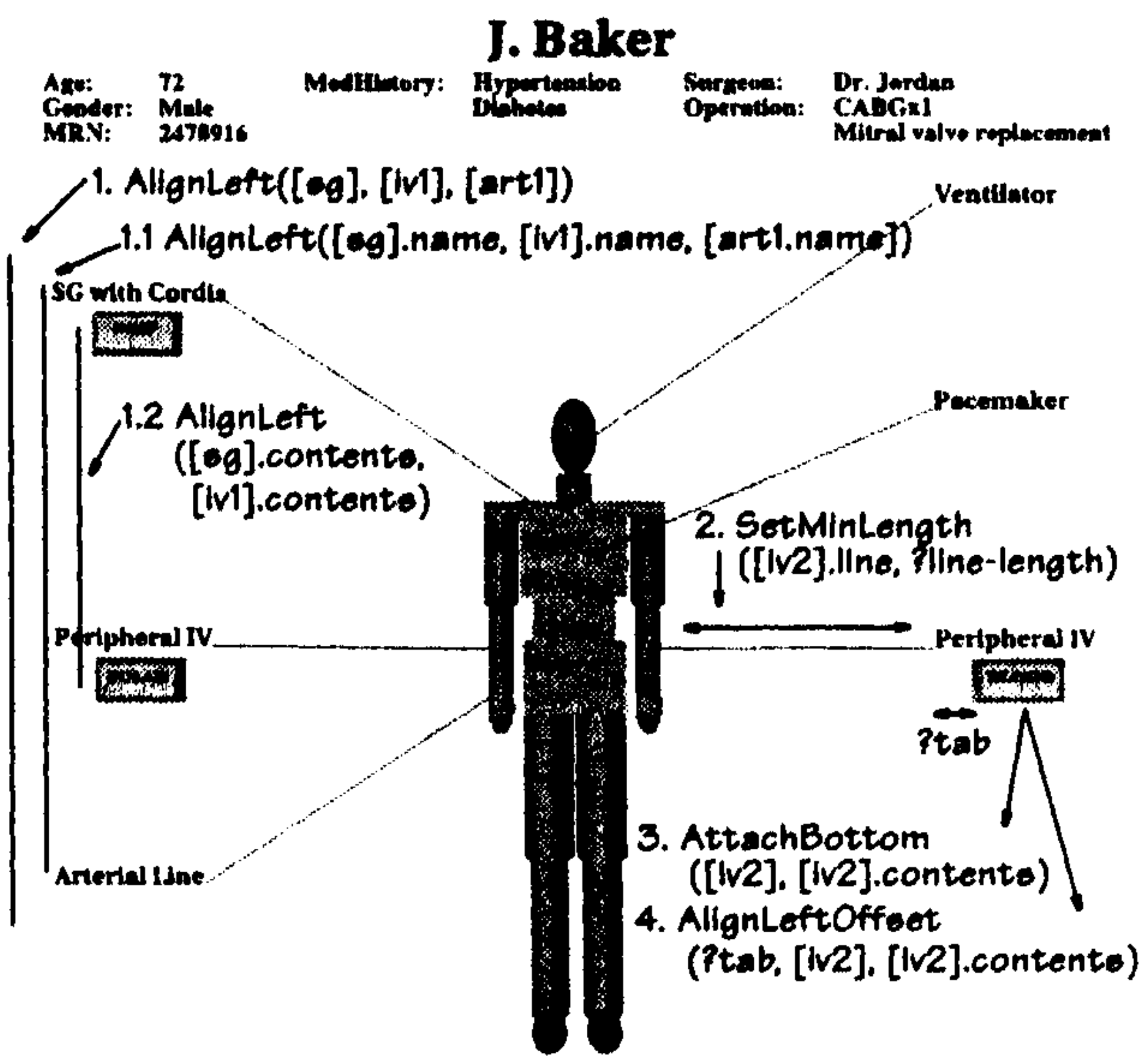

J. Baker
Age: 72
Gender: Male
MRN: 2478916
MedHistory: Hypertension Diabetes
Surgeon: Dr. Jordan
Operation: CABGx1 Mitral valve replacement
1. AlignLeft([sg], [iv1], [art1])
1.1 AlignLeft([sg].name, [iv1].name, [art1.name])
1.2 AlignLeft ([sg].contents, [iv1].contents)
2. SetMinLength ([iv2].line, ?line-length)
3. AttachBottom ([iv2], [iv2].contents)
4. AlignLeftOffset (?tab, [iv2], [iv2].contents)
?tab
Ventilator
SG with Cordis
Pacemaker
Peripheral IV
Peripheral IV
Arterial Line

Figure 3. Present patient overview to nurse (annotated)

ments such as color and shape).

Aiming to create a coherent visual discourse from scratch, our work involves both visual composition and transformation. Thus, we have designed a more sophisticated visual planning approach. This approach, implemented in PREVISE, is based in part on two planning systems: DPOCL [Young etal., 1994] and SIPE IWilkins, 1988; Wilkins et al., 1994]. DPOCL is the first system to explicitly address top-down action decomposition with partial-order planning, while SIPE can plan in a reactive environment. From DPOCL, PREVISE inherits the top-down action-decomposition strategy and amplifies it to accommodate object-decomposition; and from SIPE, PREVISE partly adopts its plan and action representation formalisms, but further expands them to allow more knowledge rich representations.

3 Example

We use one complex example, shown in Figure 1 and Figure 2, to illustrate the characteristics of visual planning. In this example, our task is to present a patient's information to a nurse after the patient's coronary artery bypass graft (CABG) operation. As the final presentation contains coordinated text, speech, and graphics, here we only concentrate on how the graphics presentations are planned.

In this task, PREVISE must accomplish two goals. The first goal is to create an overview of patient information, and the second is to elaborate the patient information details based on the created overview. To achieve the first goal, PREVISE plans to construct a structure diagram (Figure 1) that organizes various information (e.g., IV lines) around a *core* component (e.g., represented by the patient's body). This decision is made based on the fact that nurses prefer to see all information arranged relative to the patient's body. In a top-down design manner, PREVISE first creates an "empty" structure diagram. This empty diagram is then defined through its individual components by recursively partitioning and encoding the patient information into different groups. As shown in Figure 1, the patient's demographics information, including name, age, and gender as a group, is encoded as the *heading* of the diagram; the patient's physical body serves as the *core,* and the rest of the information is arranged around the core as diagram *elements.* To express the partial designs and their refinement, PREVISE uses variables and constraints to represent the progressively refined diagram at different levels of detail. In addition, PREVISE must formulate and satisfy a set of spatial constraints to determine the sizes and locations of various diagram components (Figure 3).

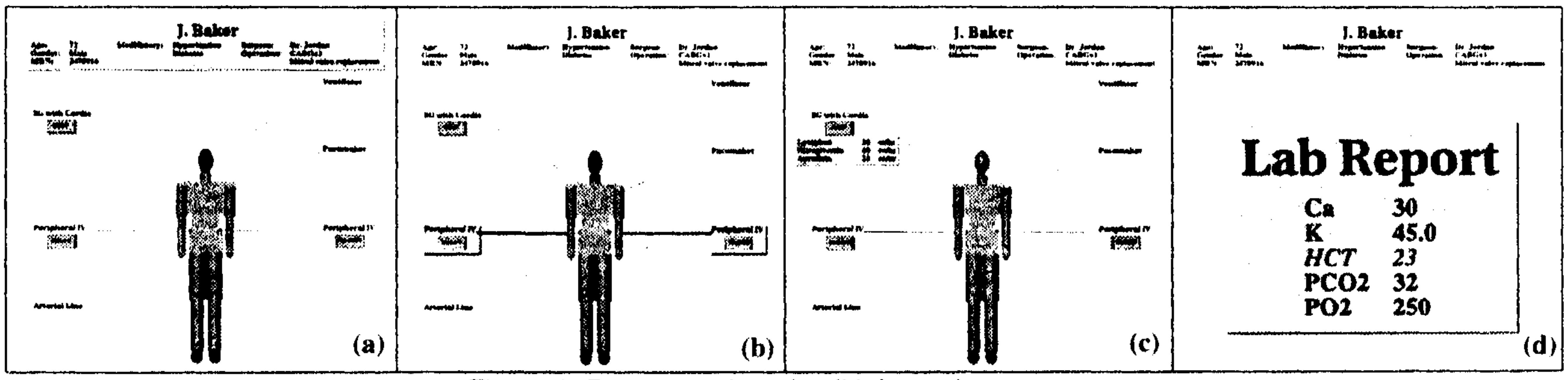


Figure 2. Present patient detail information to nurse

To accomplish the second goal, PREVISE plans a series of visual actions to allow certain information to be reinforced or revealed based on the overview. Figure 2(a-b) are created to reinforce the patient's demographics information and ivs using the visual action Highlight, while Figure 2(c-d) are planned to reveal the drip (intravenously administered drug) and lab report details. To introduce new information (e.g., drip details) into an existing display, PREVISE reasons about the spatial arrangement of existing objects and the placement of new objects. Finally, PREVISE ensures that all visual actions are temporally coordinated to produce a coherent presentation; for example, the highlighting on the demographics in Figure 2(a) should be turned off before the ivs are highlighted in Figure 2(b).

4 Visual Planning

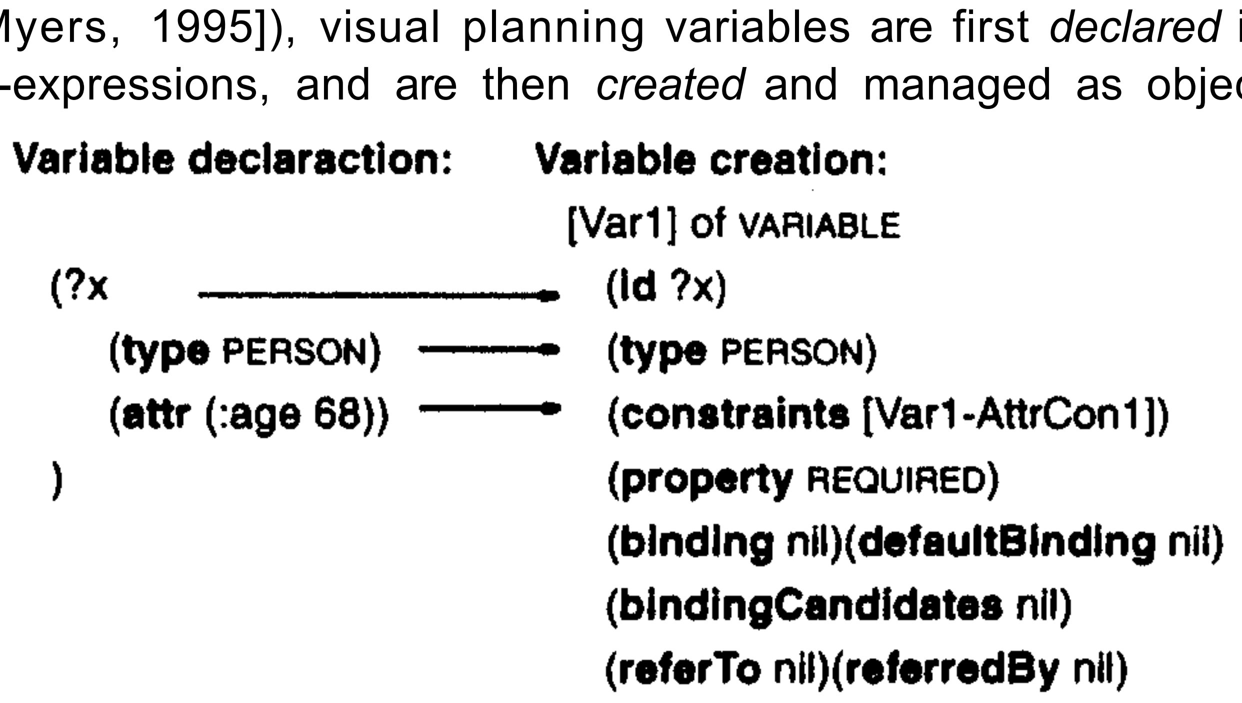
In this section, we concentrate on illustrating four distinct visual planning features and explain how they aid visual design. 7b facilitate a flexible and efficient planning environment, we first present a knowledge-rich and object-oriented representation formalism for visual planning. Using this representation, we describe how to explicitly employ object decomposition with action decomposition to simplify visual synthesis. To create both temporally and spatially coherent presentations, we address temporal and spatial reasoning issues in visual planning.

4.1 Visual Planning Representation Formalism

Using a top-down design strategy, a visual planning process must deal with partially specified visual plans at multiple levels of abstraction. To capture and manage these complex partial plans, we have developed a knowledge-rich object-oriented representation formalism based on previous work (e.g., [KRSL, 1993; Wilkins and Myers, 1995; Tate, 1996J). Specifically, our representation formalism permits the efficient usage of complex planning variables and constraints, and allows a rich expression of planning operators (visual actions). For illustration purpose, all examples given below are presented in a simplified frame-like representation formalism, where brackets [ ] are added around symbols to indicate object instances.

Planning Variables and Constraints

Unlike any of other planning variables used in complex planning systems (e.g., [Curric and Tate, 1991; Wilkins and Myers, 1995]), visual planning variables are first *declared* in s-expressions, and are then *created* and managed as object



```
Variable declaraction:      Variable creation:
                             [Var1] of VARIABLE
(?x  ──────────────────→     (id ?x)
   (type PERSON) ──────→     (type PERSON)
   (attr (:age 68)) ───→     (constraints [Var1-AttrCon1])
)                            (property REQUIRED)
                             (binding nil)(defaultBinding nil)
                             (bindingCandidates nil)
                             (referTo nil)(referredBy nil)
```

Figure 4. Variable declaraction and creation

instances. Figure 4 shows how a PREVISE variable may be declared with a symbolic id, a specific binding type, and a set of constraints. The symbolic id can either be in a form of ?x or $?y to distinguish a single valued variable (x) from a multi-valued one (y). When created, a variable instance is assigned a binding property to indicate how it should be managed [KRSL, 1993]. For example, a REQUIRED variable must be bound during planning, while an OPTIONAL variable may not be bound at all through the entire planning process. A variable may be created with or without a binding, a set of bindingCandidates, or even a defaultBinding. Moreover, this variable instance may *refer* to another variable instance or be *referred* by others during planning.

Having a separate variable declaration and creation eases both knowledge encoding and planning. In particular, variables are declared in s-expressions during knowledge encoding without dealing with the details of object creation and management. On the other hand, variables are easily handled as objects in planning without repeatedly processing complex symbolic representations. In addition, our visual planner can rely on various variable attributes described above, including variable property and references, to efficiently decide when and how to update variables. For example, using the variable reference information, if a variable binding is updated, so are all the variables that refer to this one.

It is worth noting that we also allow a special type of *dynamic variables* in visual planning. During planning, these variables may be continuously updated by a numerical constraint solver called STM [Gleicher, 1994]. Hence we refer to them as to STM-VAR. Unlike dynamic variables in other systems (e.g., [Wilkins and Myers, 1995]), a STM-VAR is more flexible in use (e.g., we do not need to explicitly specify its rebinding), and more efficient in representation. For example, a STM-VAR, used to represent a 3D bounding box, can be used to capture the changing geometry of a 3D object through five other variables (center, objCenter, width, height, and depth).

In visual planning, a PREVISE variable is usually accompanied by a set of constraints, which are also handled in the similar fashion as variables. In other words, visual planning constraints are specified initially in s-expressions, and are instantiated and managed as object instances during planning. To facilitate constraint management, we classify constraints based on their *origination* (e.g., META or SUFFICIENCY constraints in [Tate, 1996]) and *duration* (e.g., ONE-TIME or ALWAYS constraints in [KRSL, 1993]). Moreover, we assign constraints with *strength* (e.g., REQUIRED or PREFERRED) and *type* (ATOMIC or ABSTRACT) to organize them into a hierarchy [Borning etal., 1992). This constraint hierarchy not only allows object relationships to be expressed at multiple levels of abstraction, but also allows for a more efficient constraint management (see Sections 4.3 and 4.4).

Visual Action

In visual planning, a visual action captures both the properties of a planning operator and a visual technique. As a visual technique, a visual action can be a *formational* action that creates a visual object from scratch (Figure 5a),

```
DesignTableChart (is-a FORMATION-ACTION)                          (a)
 (operands (?x (type DOMAIN-OBJECT) (?t (type TABLE-CHART)))
  (localParameters (?heading (type VISUAL-UNITY)
                             (property OPTIONAL)) ...)
  (purposes ENCODE | TABULATE)
  (effects (effect1 (Encode ?x ?t)) (effect2 (Table ?t)))...
Move (is-a TRANSFORMATION-ACTION)                                 (b)
 (operands (?v (type VISUAL-OBJECT)))
 (localParameters (?src (type VECTOR)) (?dest (type VECTOR)))
  (purposes TRANSFORM | REPOSITION)
  (preconditions (cond1 (Existing ?v)) (cond2 (At ?v ?src))...)
  (effects (effect1 (At ?v ?destination)))...
```

Figure 5. A visual action definition

or a *transformational* action that modifies an existing visual object (Figure 5b). Since formational actions do not actually perform graphics rendering, they are not included in the final plan but their results might be. For example, the formational action, DesignTableChart, itself does not appear in the final plan, but its result—the created table chart may appear in the final plan with a Display action.

We also assign purposes to each visual action to summarize its functions at different levels of abstraction. For example, the purposes specified in the action Move indicate that it can be used to transform a visual object in general, specifically to reposition a visual object (Figure 5b). In addition, we use the purposes to index visual actions and create partitioned search space to reduce search time. This helps us cope with a large number of visual actions efficiently during planning. For example, when searching for a proper visual action to accomplish a transformation task, PREVISE only searches among the visual actions that have Transform as one of their purposes. Otherwise, PREVISE must examine the postconditions *of all* visual actions to find a match.

Much like a SIPE operator [Wilkins and Myers, 1995], visual action arguments are represented as variables with constraints on their binding types or properties. For example, the variable ?heading is optionally bound to a particular visual object (Figure 5a). But unlike SIPE, visual action arguments are separated into two groups: operands and local parameters. Whereas *operands* provide the uniform interface to access an action, *local parameters* describe a set of attributes specific to that action. In particular, formational actions use operands to specify their input and output (e.g., ?x is the input and ?t is the output of DesignTableChart in Figure 5a), and transformational actions use operands to indicate their recipients (e.g., ?v of Move in Figure 5b). On the other hand, both formational and transformational actions use localParameters to record all needed parameters to complete the action (e.g., ?heading of DesignTableChart, or ?dest of Move). Separating the operands from local parameters simplifies the action instantiation process since PREVISE needs to consider only the operands during this stage. This allows the instantiations of local parameters to be delayed; for example, PREVISE is not concerned with local parameters, such as ?dest (the destination of the movement) in Move, at a high level of the design.

To simplify the planning process, plan goals in PREVISE are also specified similar to actions. For example, the communicative goal to create a summary of patient information, achieved in Figure 1, is notated as a rhetorical act, Summarize<?patient-info>. Based on the domain-specific nurse preference rule, this general act is then refined to a visual goal Structure<?patient-info> that requires all information to be structured in a specific way. This visual goal is in fact an abstract visual act, which can be accomplished by other visual actions (e.g., action DesignStructureDiagram) [Zhou and Feiner, 1998].

4.2 Object Decomposition

As a planning operator, a visual action may be a *primitive* action that can be directly executed by a plan agent, or a *composite* action that contains a set of partially specified subplans and must be replaced by the subplans during planning, PREVISE usually uses composite actions to sketch a design at a high level, and refines the vague parts of the design into more detailed ones using primitive visual actions. During such a design refinement, action and object decomposition may both be required. For example, a DesignTableChart action may be decomposed into a set of subactions that define individual table components. In the meantime, the input (the data ?x) used to produce the table chart must also be decomposed into smaller units that can be used by the subactions. Although in certain cases object decomposition could be implicitly handled by action decomposition, entangled action and object decomposition makes visual planning extremely difficult (e.g., a data object may be decomposed into different subparts under different situations). Thus, we explicitly introduce object decomposition in visual planning

```
DesignTableChart (is-a FORMATION-ACTION)
  (actionDecomSchemata [actD1]...)
  (objDecomSchemata [objD1] [objD2] [objD3]...)
  (objDecompPreferences
    (preference1 (:condition (is-itemize ?x)) (:prefer [objD1]))
    (preference2 (:condition (is-overview ?x)) (:prefer [objD2]))
    (always [objD3]))
[actD1] of ACT-DECOMPOSITION-SCHEMA
   (subactions (:loop ?i (:range 1 ?n)(:update (bind ?i (+ 1 ?i)))
     (Subaction<?i> (:expr (DesignVisRep ?x<?i> ?t<?i>)))))
[objD1] of OBJECT-DECOMPOSITION-SCHEMA
  (objId ?x) (numParts ?n = :(get-numOfIndividual))
  (subParts (:loop ?i (:range 1 ?n) ?x<?i> = :(get-individual ?i)))
[objD2] of OBJECT-DECOMPOSITION-SCHEMA
  (objId ?x) (numParts ?n = :(get-numOfGroup))
  (subParts (:loop ?i (:range 1 ?n) ?x<?i> = :(get-group ?i)))
[objD3] of OBJECT-DECOMPOSITION-SCHEMA
  (objId ?t)
  (subParts (:loop ?i (:range 1 ?n)
     IF (is-identifier ?x<?i>)) THEN (put-heading ?t ?t<?i>)
     ELSE (put-cells ?t ?t<?i>)))
```

Figure 6. A visual action and its decomposition schemata

using a set of object decomposition schemata.

An object decomposition schema uses objectId to identify the object to be decomposed, subParts to specify a set of components that the object is decomposed to, and numParts to indicate the total number of subparts (Figure 6). Unlike action decomposition where only *one* decomposition schema can be used at one time, *more than one* object decomposition schemata may be applied simultaneously. For example, PREVISE may use [objDl] in Figure 6 to decompose the data ?x, but *always* uses [objD3] to determine the structural relationships between the table chart itself (?t) and its components (?t<?i>). To determine which and when an object decomposition schema should be used, PREVISE uses preference constraints stored in objDecompPreferences. Moreover, variables are used extensively in decomposition schemata to express partial plans and objects, or to represent unknown situations (e.g., ?n).

In general, two types of object decomposition occur in visual planning. In the first case, a completely specified object (e.g., a piece of data to be conveyed) needs to be decomposed into smaller units to be manipulated (e.g., decomposition schemata [objDl] and [objD2] in Figure 6). In the second case, a partially specified object (e.g., a visual object to be defined) must be decomposed into subparts so it can be refined through the subparts (e.g., [objD3]). Both types of object decomposition promote a simpler and more general knowledge encoding and management.

Using the first type of object decomposition, we can easily handle the uncertainty involved in action decomposition. For example, during knowledge encoding, the number of subactions in [actD1] may be unknown, depending on how the data (?x) will be processed in the actual planning process. In this case, before instantiating subactions in [actD1], PREVISE can establish the needed variables (e.g., ?n) by selecting an object decomposition schema (e.g., [objDl]) based on objDecompPreferences (e.g., preference¯!). This approach allows a simple and general representation of action decomposition, which only needs to specify the unknowns using variables (e.g., ?n in [actDi]).

The second type of object decomposition also helps generalize and simplify action decomposition. Without the object decomposition schema [objD3], for example, we must replace the general action DesignVisRep with more specific subactions, such as DesignTableHeading and DesignTableCell, to define various table constituents. In addition, we must consider all the possible combinations of these specific subactions to construct different subplans (e.g., a subplan may require a subaction DesignTableHeading, but another may not). This not only requires a number of different actions to be defined, but also increases the complexity of knowledge management. Considering the case of defining a new action DesignBarChart, we need to introduce a set of new actions (e.g., DesignAxes and DesignBar) for various bar chart constituents. We must also ensure that each subaction is supplied with the proper data components to guarantee the design correctness. For example, only quantitative data components may be involved in the subaction DesignBar.

Therefore, separating the object decomposition from the action decomposition allows simpler and more general representations for action decomposition. More importantly, these simpler and more general representations improve PREVISE'S applicability by easing its tasks of knowledge encoding and management.

4.3 Temporal Reasoning

During a visual presentation, visual actions can occur concurrently or over extended time intervals. To create a temporally coherent visual presentation, we have integrated temporal reasoning into PREVISE to ensure that visual actions are temporally coordinated. Compared to other systems (e.g., [Tate etal., 1994; Wilkins and Myers, 1995; Andre and Rist, 1996]), PREVISE uses multilevel topological and metric time constraints to describe actions at a finer granularity during planning generation. It also employs a novel scheduler to ensure that all temporal constraints are met during planning execution.

Temporal Constraint Specification

PREVISE deals with two types of temporal constraints: *Inter-action* constraints specify temporal relations *between* two visual actions, and *intra-action* constraints describe temporal relations *within* a visual action.

Inter-Action Temporal Constraints. PREVISE uses topological constraints to represent temporal relationships between two visual actions qualitatively. These constraints can be represented as either time-point or time-interval constraints. In general, PREVISE allows three types of time-point constraints: BeforeAt, AfterAt, and EquatAt; and permits time interval constraints, containing any subset of the thirteen basic temporal relations defined in [Allen, 19831. When described in time-point constraints, visual actions may be considered *instantaneous.* In contrast, visual actions have distinct starting and finishing times when specified using time-interval constraints.

Allowing both time-point and time-interval constraints not only enables PREVISE to represent different temporal relationships accurately, but also helps to handle temporal constraints efficiently by exploiting a multilevel constraint representation. Usually, we can use concise time-point constraints to specify incomplete temporal relations at a high level, and employ time-interval constraints to express more refined temporal relationships at a low level. For example, PREVISE can use a simple time-point constraint to assert that action A must start before B at a high level, without knowing their finishing times:

(BeforeAt A B)

Later, this constraint can be refined using one of the three more specific time-interval constraints based on their finishing times:

1. A finishes before B: (Overlap A B)
2. A finishes after B: (Contain A B)
3. A and B finishes at the same time: (FinishedBy A B)

This multilevel temporal constraint representation helps avoid computationally complex temporal reasoning at a high level, hence improves planning efficiency.

Intra'Action Temporal Constraints. In addition to temporal constraints between visual actions, we also describe temporal relationships within an action. Unlike inter-action temporal relationships, these relations are described quantitatively using metric time constraints (usually in seconds).

In general, a PREVISE action has a startTime and an endTime to regulate when and how long the desired visual effects should appear on the screen. But we add subtime intervals in a transformational action to describe its animation subacts. In particular, animOnDuration controls the time taken to turn on the desired visual effects (e.g., gradually changing the color of an object to highlight it), holdingDuration specifies how long the current effect should remain on the screen (e.g., holding the highlighting effect), and animOffDuration limits the time taken to reverse the visual transformation (e.g., turning off the highlighting). Using these subintervals, we can describe and control a finer-grained visual action and its execution. Moreover, we can specify an animation with its reverse without explicitly introducing a set of undo actions (e.g., unhighlight).

To facilitate temporal media coordination (e.g., coordinating a graphics animation with speech) in a multimedia presentation, we also allow more flexible time-window constraints. For example, we may specify that a Highlight action needs a minimum of 1s or maximum of 2s to turn on the highlight, and another 3s to 4s to hold the highlighting. To coordinate the highlighting with speech, a media coordinator can use the time window to compute a time interval acceptable for both graphics and speech.

Temporal Constraint Satisfaction

We deal with temporal constraints in both plan generation and execution. In plan generation, we use a simple constraint solver to process qualitative time constraints based on transitive closures. Conversely, we use a constraint solver based on *Metric/Allen Time System* (MATS) [Kautz, 1991] to process quantitative temporal constraints.

Execution Scheduler. In plan execution, we have implemented a time queue to schedule visual actions. All visual actions are first entered in the time queue by their starting times. The scheduler then uses a global alarm clock to invoke actions when their starting times are reached. A local timer is also maintained within each visual action to signal its termination when its finishing time approaches.

This approach works fine until this problem arises: Two closely scheduled actions (e.g., actions A and B in Figure 7a) may overlap as the scheduler cannot guarantee *a full* stop in previous action (e.g., A) when its local timer expires. This is because the local timer does not account for the time spent for executing various implicit finishing acts. For example,

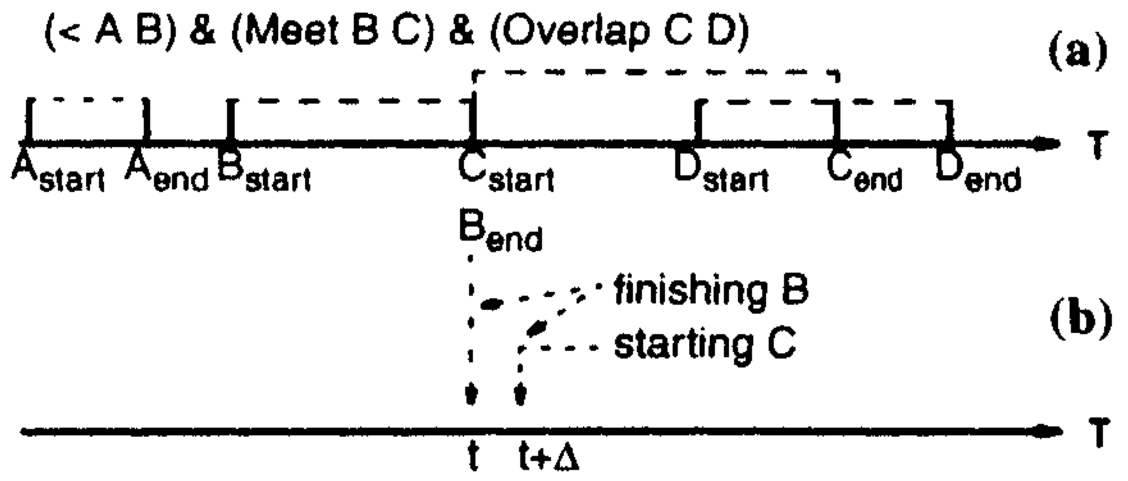


Figure 7. Time queue for plan execution

action A may call an *instantaneous* undo act (animOffDuration is 0.0s) when its local timer expires. Thus, there is no guarantee that A's undo act will be finished *before* B starts.

To fix this problem, each action is required to signal the scheduler when it is truly finished. In addition, we insert a dummy finishing act for each action in the time queue by its finishing time to ensure that the global clock be stopped if the previous action is not finished. As shown in Figure 7(a), when the global clock reaches the dummy act A_{end}, it would not be advanced to action B_{8tart} until it receives A's finishing signal.

The above approach only fixes half of our problem: it works for actions scheduled one *after* another (e.g., A and B in Figure 7a), but not for actions scheduled *right next* to each other (e.g., B and C). In this case, the plan agent is expected to execute two tasks *simultaneously:* finishing the previous action (B) and starting a new action (C). Since it is physically impossible for uniprocessor machines to process two tasks at the same time, the tasks will be executed in a nondeterministic order. This may result in undesirable visual effects. Suppose B and C are both highlighting actions, and B must finish by removing its highlight *before* C starts to put on a new highlight. Because of the nondeterministic execution order, C might be started *before* B finishes to cause an undesired visual effect: two objects highlighted at the same time instead of in sequence.

To ensure desired visual effects, we add *sub-order* temporal constraints to serialize simultaneous actions using heuristics. For example, one heuristic rule in PREVISE asserts that all dummy finishing acts precede any other action scheduled at the same time. In the above example, the plan agent will process B_{end} before C_{start}, as if the time point t is *expanded* into a time interval [t, t+A] (Figure 7b). This ensures that all objects in action B are unhighlighted before any new object is highlighted in action C.

4.4 Spatial Reasoning

PREVISE performs spatial reasoning in two situations. In *spatial composition,* PREVISE regulates the size and placement of visual objects to ensure a valid visual composition. In *spatial transformation,* PREVISE controls the spatial modification of existing visual objects and the integration of new visual objects to maintain a coherent visual transformation.

Spatial Composition

A visual composition is considered *valid* if all syntactic constraints are satisfied during visual object synthesis [Zhou, 1998]. Among these syntactic constraints, some regulate spatial relationships between visual objects. Figure 3 is annotated to show a set of spatial constraints that must be satisfied in a structure diagram. Moreover, these constraints are specified at different levels of abstraction to capture multi-level spatial relationships. For example, constraint 1 is an abstract spatial constraint, defined at a high level to describe vague spatial relationships between complex visual objects. In contrast, constraints 1.1 and 1.2 express more concrete visual relationships. To be evaluated, an abstract constraint (e.g., constraint 1), must be replaced by a set of more concrete constraints (e.g., constraints 1.1 and 1.2). One distinct advantage of using abstract constraints is to achieve planning efficiency by postponing overwhelming details involved in lower level constraints to a later time.

By evaluating a set of constraints, PREVISE can determine the size and placement of visual objects involved. For example, the locations or sizes of various texts in Figure 3 can be determined. In PREVISE, we model spatial constraints using mathematical equations and inequalities, which are eventually solved by STM using a numerical optimization method. Since the optimization method requires a set of proper initial values, we must supply these values for STM to start with. For example, we need to supply the proper initial values for ?line-length and ?tab in constraints 2 and 4 (Figure 3). Currently, these values are obtained based on empirical analyses of many existing graphical representations (e.g., hand-made or machine-made structure diagrams). For example, to best illustrate the spatial ratio between the patient body and the lines, we have learned that the length of various lines in the picture is usually at least 1/3 of the diagonal length of the body's bounding box.

Spatial Transformation

In addition to ensuring a valid visual composition, PREVISE also uses spatial constraints to control the integration of new information into an existing presentation. In one approach, PREVISE directly adds the new information to the existing scene as *visual extensions* of existing objects. For example, to reveal drip details (Figure 2c), PREVISE directly adds a pull-down menu as an extension of the drip button in the overview (Figure 1). To determine the size and the placement of new objects (e.g., the pull-down menu) in relation to the existing objects (e.g., the button), PREVISE reasons about the spatial geometry of the existing scene, including the objects* size, orientation, and topology, by issuing queries. It then formulates constraints based on design heuristics. In our case, based on the current geometry of the drips button, PREVISE formulates spatial constraints to regulate the size and position of the added pull-down menu.

To avoid unnecessary spatial rearrangement, we also assert a set of spatial constraints *in advance* to prepare Ibr potential visual changes. For example, a button is usually expected to bring up a pull-down menu when pressed. Therefore, when a button is created, a spatial constraint is asserted to ensure that there is enough room reserved below the button for placing a pull-down menu (e.g., the space below the drips button in Figure 3).

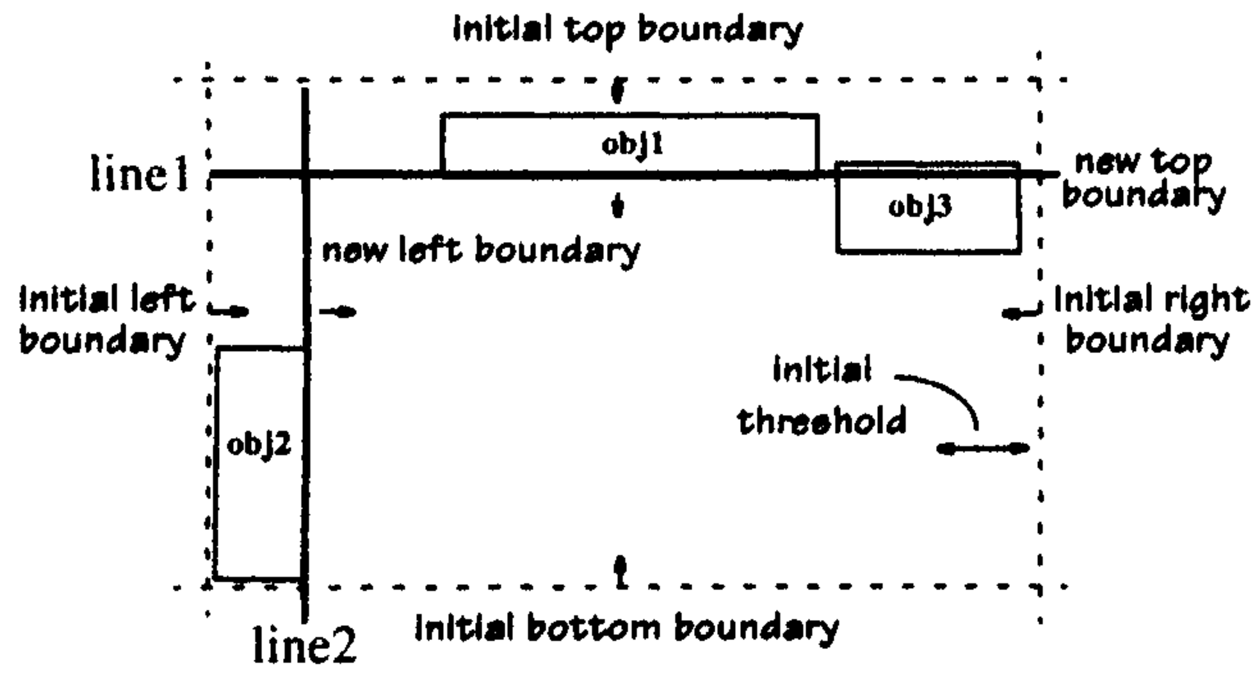


Figure 8. Space management diagram

In general, directly adding new objects to the existing scene is relatively simple since PREVISE deals with a confined space with rigid spatial constraints (e.g., placing a pull-down menu near a button). However, in many cases, PREVISE may need to modify the existing scene dramatically for integrating new information. In this case, PREVISE must determine how to make spatial changes for the new objects. For example, to produce Figure 2(d), PREVISE decides to keep the table chart at the top (e.g., name, age, and gender) of Figure 2(c) to provide the necessary context information, while replaces the rest of representation with the lab report.

PREVISE currently deals with relatively simple space-management cases. Our approach assumes that all existing visual objects will be replaced except the objects that must be kept to provide necessary background or context information. Once PREVISE determines what to keep or to remove, it will plan the size and the placement of the new objects (e.g., the table chart for lab report) using an iterative-adjustment algorithm. To utilize space efficiently and produce a balanced layout, the algorithm assumes that the kept objects usually reside in the shaded area to leave the middle area for the new objects (Figure 8).

The shaded areas are initially defined by a set of threshold values to guarantee that at least 2/3 of the display area in the middle be reserved for the new visual objects. The algorithm then iteratively computes the bounding box for each object kept in the scene and determines the region containing this object. If the object falls in only one of the eight shaded regions (e.g., objl and obj2 in Figure 8), the algorithm adjusts the current boundaries by pushing them toward the center to define unoccupied space. For example, the initial top boundary is pushed down into line 1, and the initial left boundary becomes line 2 in Figure 8. If the object does not completely fall in any of the eight regions (e.g., obj3) and the threshold values arc adjustable, the algorithm recursively increases the current threshold values to recompute new boundaries. If the threshold values are not adjustable, the current existing objects may be modified to create enough room for new objects. Eventually, the algorithm returns four boundaries to define the dimension and position of the area for placing the new objects.

5 Implementation

PREVISE is implemented using both CLIPS [JSC-25012, 1993] and C++, currently running on SGIs and PCs under Windows NT. The rendering component is written in C++ and Open Inventor, an object-oriented 3D interactive graphics toolkit [Wernecke, 1994). On a SGI Indigo 2 with a 250 MHz R4400 processor, it takes about 25 seconds to plan the overview of patient record shown in Figure 1, and about 45 seconds to plan the entire detail view of patient record, partly shown in Figure 2.

6 Conclusions & Future Work

In this paper, we have presented a practical visual planning approach to automated visual presentation design. In particular, we model visual actions as planning operators, and visual design principles as planning constraints. On top of our core top-down hierarchical decomposition partial-order planning approach, we add a set of visual planning features. These features include a powerful visual planning representation, an explicit object decomposition method, and temporal and spatial reasoning capabilities. Moreover, this approach is implemented in a planner, PREVISE, as part of our automated visual presentation testbed system.

Currently, we are working in two areas to improve the visual planning approach. To allow user interaction during planning generation and execution, we are planning to incorporate reactive planning strategies [Wilkins et al., 1994]. For example, users may suggest changes to the design decisions made by PREVISE, or interactively alter the course of the execution to selectively view the presentation (e.g., executing visual actions out of sequence). Thus, our current approach must be extended to recognize the inadequacy of a current plan, and correct it to meet the new conditions.

To perform spatial analysis and management for more complicated situations, we would also like to enhance the spatial reasoning capability. For example, developing a general and efficient algorithm to query the spatial density of a scene so we can place new objects on the location where the spatial density is low to avoid possible object occlusions.

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