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An Implementation of Multiple Inheritance in a Persistent Environment

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An Implementation of Multiple Inheritance in a Persistent Environment

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Introduction

An Image Data Processing System [2] (IDPS) is documented as an object-oriented pictorial database system comprising an interactive graphical toolkit and an hierarchical database model incorporating multiple inheritance.

The database hierarchy is based on the notion of a taxonomy of superobjects and subobjects and composition inheritance links within the actual pictorial representation of an object. A query language permits retrieval of objects by matching textual attributes in a given query with the values of database objects.

Using the atomic graphical objects line, circle and box, arbitrarily complex pictures maybe built up to define a object's graphical representation. This method of specifying objects allows for graphical inheritance through inclusion which may be recursive.

IDPS is a Senior Honours (1987) project implemented in PS-algol [7] at the University of St. Andrews as a course requirement for the B.Sc. degree in Computational Science.

1. Historical Perspective

Sutherland's "SKETCHPAD" [18] provided the inspiration for our system. Advances in human-computer interfaces have provided us with conceptually simpler and more flexible graphical development systems and toolkits. Improved workstation technology offers a wide range of facilities to the programmer and hence any implementation of the IDPS should be able to support a comprehensive set of picture manipulating functions to provide that higher degree of flexibility.

Hierarchical data models [3,9,13] provide a natural mechanism whereby subclasses of objects inherit all the attributes of their superclasses. The Smalltalk-80 implementation [10] offers only single-valued attribute inheritance. Subsequent proposals for multiple inheritance are discussed in [3]. The semantics for this latter model and a means of inheritance type-checking are discussed in the implementations of Galileo [1] and Amber [6]. Many existing hierarchical systems such as Trellis [15] successfully incorporate a particular solution to the problem.

Traditional database management methods are not ideal for manipulating pictorial data as

1. such data is continuous and two dimensional,
2. the result of a database query is alphanumeric rather than graphical,
3. different operations are required to deal with pictorial data.

Consequently several difficulties arise when attempting to formalise the combination of these two models of data. Particular techniques are required to provide graphics functions. Symbol hierarchies, modelling transformations, display procedures and symbol operations are essential. The user interface requires a user model, a command language, on-line help facilities, quick response times to all operations, systematic menu design and facilities for feedback and screen output and layout [10,11,16].

2. IDPS: Design, Objectives & Problems

In IDPS, the traditional notion and definition of classes [8] as super- and subclasses of each other is deviated from. Instead, database records (*objects*) reside in an environment which exhibits *object/value* inheritance rather than attribute inheritance.

We have extended the hierarchical database model to incorporate a simple but powerful notion of multiple inheritance. Records of information stored in the database table are treated as objects, operations upon which are as follows:

1. creation of new objects,
2. deletion of objects.
3. updating of objects, e.g. addition of further detail to objects: extension of an object's attibute list or addition of verisimilitude to graphical representations,
4. identification of a relational formalism; through creation or editing of an object in the hierarchy a specification of parent and child relationships between objects is possible,

5. retrieval of objects by named or predicate search.

In order that the inheritance mechanism operates efficiently, all database `OBJECTs` have

1. a unique identifying name,
2. an optional short textual description,
3. links to its superobjects,
4. links to its subobjects (**not** user definable when creating a new subobject; subobject links only exist as superobject-object links when creating a *new object*),
5. a pictorial representation (the object's "scene"),
6. links to all of its instances,
7. a list of attribute name-value pairs, e.g. `(size,medium)`. IDPS treats all names and values as having type **`string`**.

The design specifications of the system are four-fold, namely

1. *database model* (requirements analysis); a general purpose pictorial database system with inheritance mechanisms. Pictorial data is generated interactively, and an abstract data representation of the pictorial information is stored together with textual information on each object.
2. *data needs* (information and object oriented structure); the definition of a database object is specified using the necessary intra- and interobject relationships.
3. *processing needs* (object structure orientation); all access operations on the database records, modes of operation and frequency of use, and graphics processing requirements are considered as internal to the schema representation. This governs the types of functions possible.
4. *storage level representation* of data in the given system; the IDPS design is concerned with superobject-subobject relationships. The actual storage level design of the data is dependent on the abstract structure for storing the pictorial representation of each object. This is based on the needs of the graphics model; simple line drawings based on atomic component manipulation are sufficient to build complex pictures [11,13]. The interface mechanism of the database schema is

used to incorporate existing scenes in the current representation. As a large number of operations are permissible upon such attributes it is necessary to strictly control the use of mouse buttons, their combinations and usage semantics. To ease the use of IDPS as little interaction is made via the keyboard as possible (textual key entries, object descriptions, etc.) while all subsystem menu calls are WIMP and menu oriented.

The conceptual model encompasses

1. *view modelling* which generates an abstract representation of the database using the specification of the requirements analysis,
2. *view integration* which integrates all possible user views into a global view of the database, i.e. the ubiquitous `UNIVERSE` object,
3. *view restructuring* which maps an integrated view of the logical structures onto the target system.

Automatic graphical inheritance [9,10] is meaningless in our implementation. It is the user's perogative to make a logical application dependent decision which defines the appearance of the object's scene; certain basic superobjects may already exhibit suitable pictorial characteristics and may therefore be included into the current scene. However, the following example (Fig.2.1) clearly demonstrates how this cannot be achieved with automatic graphical inheritance.

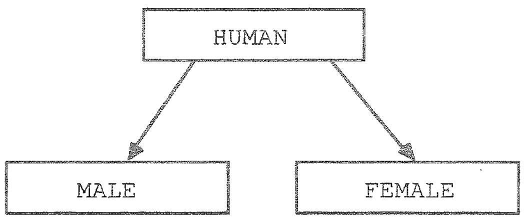


Figure 2.1

If one were to draw a skeleton for the `HUMAN`'s scene, then it should be anatomically sexed. Automatic graphical inheritance would give the `MALE` a `FEMALE` skeleton, or vice-versa (whichever is not specified). Even if the `MALE` were suitably clothed, a

closer examination (by parsing the `MALE`s inherited scenes) would reveal an inconsistency in the database inheritance mechanism. This consistency is at the root of semantic interpretation of the user model in the hierarchy. For this reason only very basic scenes need be created for each object. At any instant in time, the creation of an object defines a new subobject leaf node; this object may later become a superobject by virtue of another creation. Because of this, tangled multiple inheritance is not possible. For example in Fig.2.2 the superobject-subobject link from `D` back to `B` is not possible.

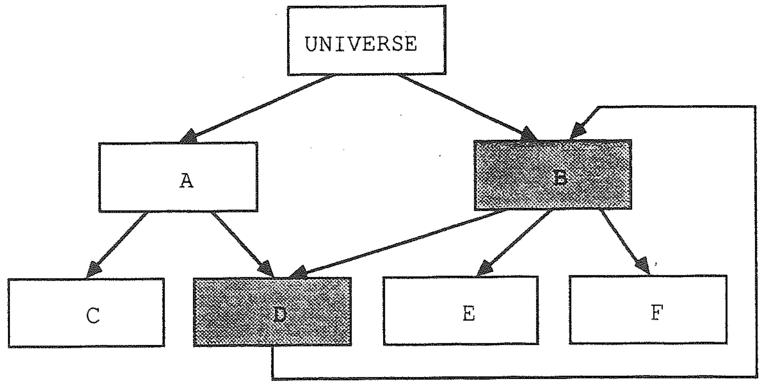


Figure 2.2

If `B` represented a barn door and `D` a barn, this example would tell us that a barn door is

1. a component of a barn, is a component of a barn door, is a component of a barn, etc. i.e. a recursive definition,
2. the attributes of the barn are (in part) derived from a barn door, but also the attributes of a barn door include those of a barn itself.

Such definitions of subobject inheritance are always recursive. The meaning of such definitions is not clear. For this reason they are not permitted.

Graphical inheritance is achieved by the user specifying scenes to be included in a object's `SCENE`. This mechanism allows a created scene to be included within itself to produce a conceptually infinitely regressive scene which is recursively defined with scale tending to zero, and positional value relative to the regression in the picture. The aim is for the user to utilise "skeletal" scenes in the hierarchy when creating a new scene. More well-defined subobjects whose scenes are inherited from their "parents" are fleshed out using the graphical editor until it meets the object's specification.

Declaration of attributes *local* to a object is possible only in a restricted sense. Any such name-value pair will be automatically inherited by a subobject specification. Local attributes of the same name as one inherited further up the graph (as in Smalltalk's single-value inheritance) are not permitted.

The abstraction techniques of *generalisation* and *aggregation* [17] are used to define the requirements of the database. Generalisation can be considered to suppress the differences between objects in a category, e.g. the domain of objects {elephant, dog, cat} and the generic object ANIMAL. Aggregation suppresses the component names and can be thought of as a relationship between objects, e.g. a person reserves a room in a hotel (relationship) and the corresponding aggregate object could be RESERVATION. Repetition of these produces an hierarchy of objects.

3. Database Model Implementation

In IDPS the generalisation is taxonomic and the aggregation can be considered as an "is-composed-of" semantic edge for the pictorial representation of an object. The conceptual model includes the generalisation and aggregation hierarchies for all concepts supporting the application view. Thus modularity is introduced. A necessary distinction is made between object and graphical attribute structuring; both views are concrete abstractions over the unified model with which the user is concerned. The object inheritance graph is acyclic (a tree) as recursive object definitions are not possible. Cycles are permitted when specifying graphical attributes of objects, i.e. the scene. Consequently the pictorial hierarchy only exists to provide an optional inheritance link for the scene attribute of an object.

Links in the database model are hence defined in two forms as

1. superobject-subobject links used for general database operations:

   <universe> ::= ø | <object>$^+$

   <object> ::= ø | <object>$^+$

   A newly initialised database has only one object, the UNIVERSE. Subsequently new objects are *all subobjects of the UNIVERSE*. In this sense, UNIVERSE is in fact a unique superclass representing the whole database.
2. composition links; each object has a pictorial representation (attribute of SCENE):

   <scene> ::= <scene>$^+$ | <atom>$^+$

   <atom> ::= <line>$^+$ | <circle>$^+$ | <box>$^+$

   i.e. SCENEs may be composed of other SCENEs or atomic objects.

These composition links are utilised in the graphical operations of the system. The scene of a object contains lists of constituent scenes (with scale and location information) and its own atomic objects. Fig.3.1 shows an example of this arrangement where TREE and ROAD denote individual collections of LINEs, CIRCLEs and BOXes which are linked to the object STREET. The object HOUSE has been graphically inherited into the new scene three times. This does not mean that STREET has three instances of the object inherited,

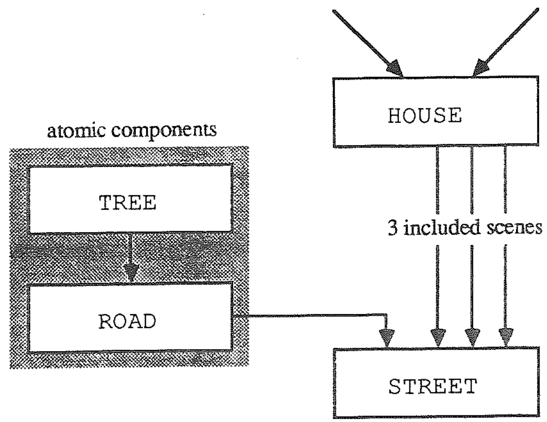


Figure 3.1

but only three instances of the *scene*. HOUSE has two superobjects in the hierarchy.

Subobjects in the database achieve automatic inheritance of single valued attributes through the generalisation hierarchy as in Fig.3.2. An inheritable attribute is one that applies to any instance (subobject only) by virtue of its membership in the superobject.

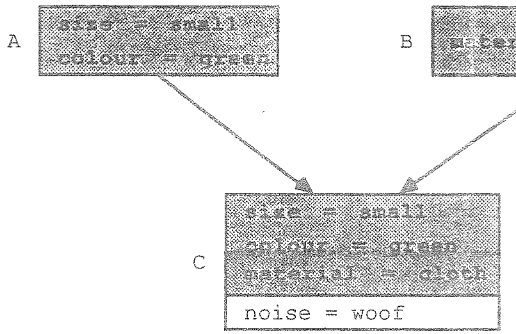


Figure 3.2

A subobject inherits all the attributes of its superobjects (multiple inheritance as above) but not their SCENE representations. The last attribute of object C happens to have been defined locally so now any object which has specified C as its superobject will inherit all four attributes. An object may have it's attribute values edited or indeed extended as part of the database maintenance process. Attribute value changes to objects in the universe will filter through to all inheriting subobjects.

Changing the representation of LEG in Fig.3.3 accordingly alters the pictorial representation of DOG and HUMAN (by composition rules). This is given that DOG and HUMAN have the same BODY and LEG. The alternative and better approach would be to create DOG.LEG and DOG.BODY, HUMAN.LEG and HUMAN.BODY as new objects and then redefine the composition of DOG and HUMAN. This example shows the care which must be taken in generalising the attributes of a object as all its subobjects will inherit these values. Superobject-subobject links between the highlighted objects can be considered a reasonable proposition, but this would mean that now BODY, LEG, ARM and MAMMALS are superobjects of HUMANS and DOGS. If this point were an absolute necessity, then the above description of the application model is incorrect - the user

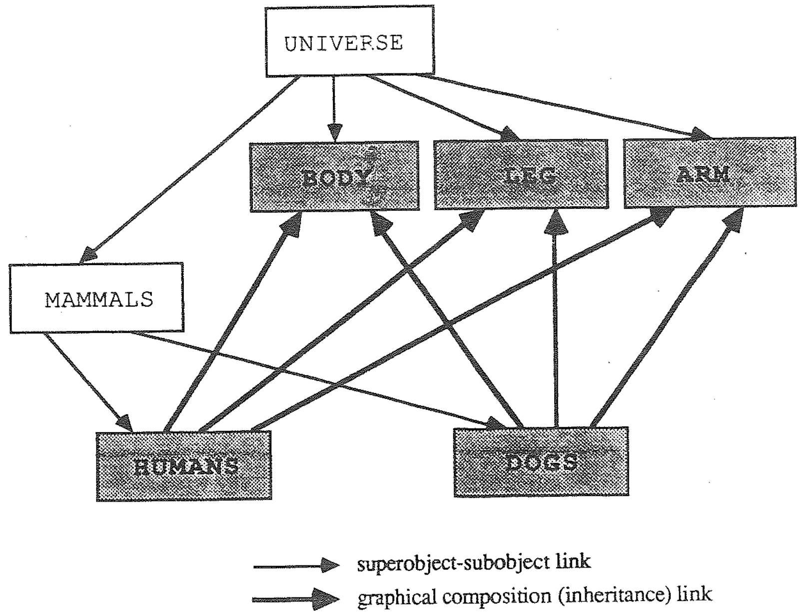


Figure 3.3

should have created a superobject BONE.STRUCTURES for example, specifying BODY, LEG and ARM as having this superobject then specifying the all new superobject relationships for objects from here. It is possible that the above hierarchy gives a more accurate description of what the user is attempting to model, and merely the graphical attributes of the three superobjects are required to complete the definition.

Duplication of what the user considers to be a submodel structure, i.e. part of the hierarchy, or creation of new objects can be used to overcome this problem. A data dictionary which may be manipulated is included within the conceptual design.

Scenes derived from the atomic LINEs, CIRCLEs and BOXes may be arbitrarily complex attributes of an object and are stored using the following abstract data representations:

```
OBJECT          (string object.name, object.description;
                 pntr super.objects, sub.objects, scene,
                      instances, attributes)

LIST            (pntr element, next)

ATTRIBUTE       (string attribute.name, attribute.value)

CONSTITUENT     (pntr object;
                 real locx, locy, scale.c)

SCENE           (pntr scenes, circles, lines, boxes)

LINE            (real x1.l, y1.l, x2.l, y2.l)

CIRCLE          (real x1.c, y1.c, radius.x.c, radius.y.c;
                 int rotate.c)

BOX             (real x1.b, y1.b, x2.b, y2.b)
```

4. Conventions & Constraints

Four windows (see Fig.4.1) are used throughout interaction, each defined as an abstract data type with capabilities for input and output of text, clearing and closing operations so that any function using them may treat the display in a uniform and selective manner.

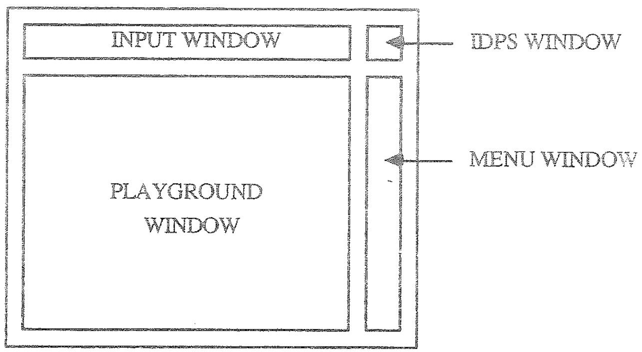


Figure 4.1

Messages to be acted upon always appear in the input window whilst displays of various forms are shown in the main playground area. All options menus appear in the rightmost window leaving the introductory system menu displayed in the playground.

The special case of the UNIVERSE object has neither a scene nor attributes; it is impossible to specify a general and *useful* attribute for this object which can still apply to subobjects.

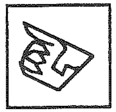
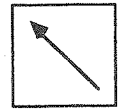
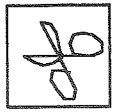
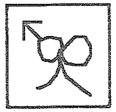
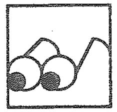
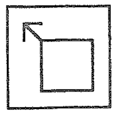
ICON	MEANING
	menu option selection
	graphics pencil
	cut out (delete) atom or scene within a scene
	tie (inherit) two scenes together
	view a scene
	move or select a portion of the scene

Figure 4.2

Six icon images shown in Fig.4.2 are used at selected points during run-time in place of the standard mouse pointer. Each indicates what the system is doing or is able to do at that point. For a user, it is far clearer what is happening at run-time by using this method. Icons are easier to understand than numerous textual messages and attention is localised at all times on one aspect of the interface.

Mouse control of system functions revolves around a simple rule-set defined as follows:

1 : select or start a function,
2 : abort, returning to the start of the current function,
3 : terminate with results and return to the previous function.

For functions whose nature demands a more complicated set of button commands, combinations of the above three are used in a consistent manner.

5. Applications & Use

The IDPS menu hierarchy shown in Fig.5.1a indicates the buildup of the system from ideas to specifications to menu entries to program (function) module development and finally implementation of tested code as live menu options.

Those functions which when selected cause visual or database updates have a secondary menu function (Fig.5.1b) which traps any accidental menu selections. At all times the OPTIONS and EDIT menus, when called, remain displayed in the rightmost window with the current option highlighted. This allows for an entirely visual option selection and verification process, keeping the user's attention focussed where it is needed.

On-line help is available at every point of keyboard data entry and also as a main menu function; each IDPS function has a screenful of information available for consultation with guides to related functions. It is important that the contents of the database are able to be catalogued in some meaningful and unambiguous form. To this end both a simple textual listing of object names and a full graphical browser are available (see also [4]). The browser, as Fig.5.2 shows, details the selected object and its respective super- and subobjects. Where there are too many super- or subobjects to be displayed in one go, a cyclic horizontal scrolling list of objects is presented. The database is *parsed* by repeatedly selecting a super- or subobject to be the new central

object (located in the centre of the display); any selected object may be "exploded" to reveal both its graphical representation and inherited attribute list.

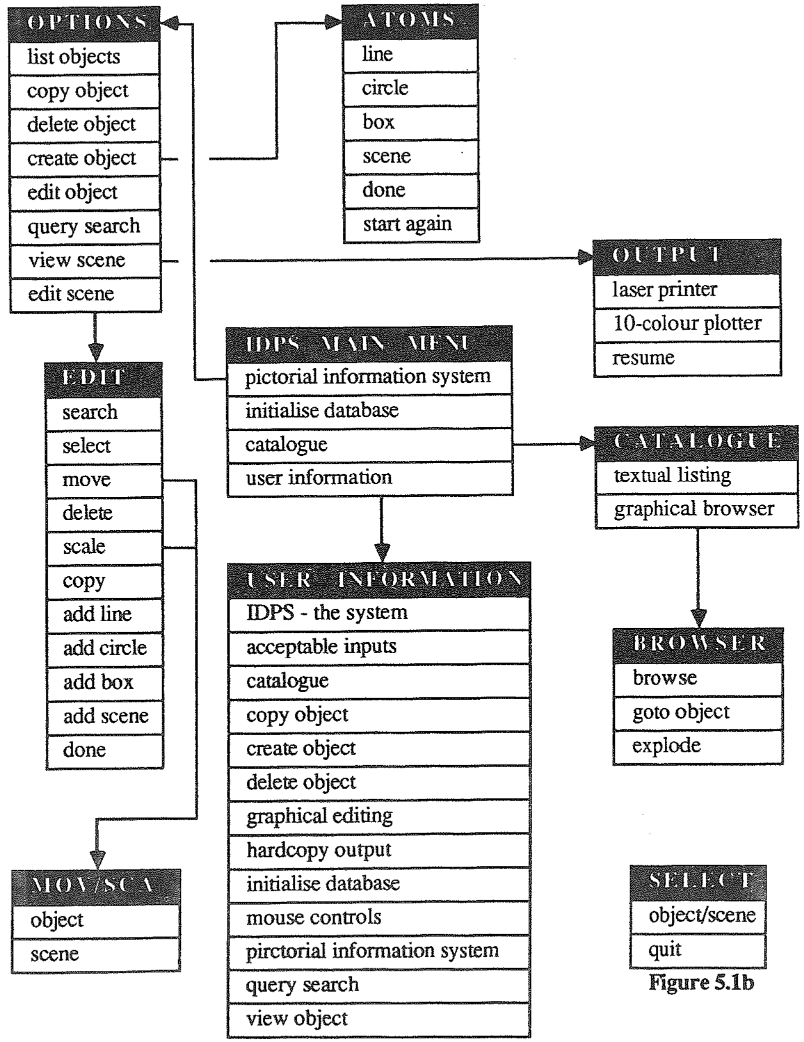


Figure 5.1b

Figure 5.1a

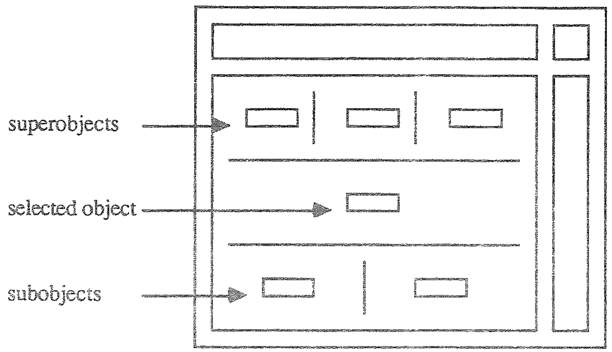


Figure 5.2

Several application areas for an IDPS were considered and these ideas have shaped the final piece of software. Of these the following are most significant: a graphical toolkit (albeit very simple) with inheritance, electronic schematic circuit modelling (transistors, capacitors, etc. may be created as resource objects to be included in a large diagram), "architectural" design, chemical modelling, cartographic modelling, biological classification, overhead slide preparation (through the hardcopy function), and database tutorials.

6. Conclusions

We have described an implementation of multiple inheritance using a model comprising two inheritance graphs. Object relationships must be kept distinct from the possibility of recursive graphical attributes.

Attributes are both textual strings and line drawings. Repetition of the database model functions upon objects allows refinement of these attributes.

Iconic cursor images used during interaction with IDPS show system status at all times. This is preferred to additional textual message displays and windows. As keyboard data entry is minimised, continuous on-line help is available (also at every new

level of menu selection).

Examination of database contents is by use of textual catalogues or more explicitly through the graphical browser; in this, a map of the precise super- and subobject relationships can be viewed in a logical manner.

Early evidence suggested that for a system as large as IDPS modular development of program source is necessary. *Static* binding of modules was chosen rather than *dynamic* (closures defined at run-time) because of the large number of permissible functions available at each stage and speed of module execution (encompassing link times, database pattern matching and closure definition). This, however, means there exists an update precedence for program modules in the database during development time. At run-time the benefits are only marginal in terms of speed but the chosen design principle holds; for smaller systems dynamic binding is preferred. Without such techniques, development of the project would have been very difficult.

One further benefit of such a scheme comes when type-checking module signatures. With dynamic closures, only at run-time can updates to modules' parameter lists be tested by an activation of the function. Should a type error arise data may be lost or indeed corrupted. By statically binding modules together (through the module update precedence list) this is overcome at the point where the closures are defined.

A slide presentation of the project to colleagues in the department included a demonstration of the possibilities of recursion in graphical attributes. A view of a house may be presented and its contents browsed by parsing the inheritance graphs. A journey through a window into a bedroom to look at a poster on a wall is possible. The picture shows our solar system which we can examine to discover the Earth, and through clouds to reveal the British Isles. Selecting this scene shows a number of cities, one of which details a map of the area. Homing in on a street scene we are confronted with several houses, the rightmost of which we recognise as out starting point. Many paths may exist in from one scene.

For more serious applications, IDPS would clearly need a far more extensive range of tools in the graphical toolkit. Extending the system for such a purpose as this is not a problem. The persistent database is updated to include a new procedure and respective menus are extended to offer the new function. The dynamic capabilities of

IDPS to match changing requirements of users is clear evidence of how important module persistence is.

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