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A DYNAMIC TEMPORAL OBJECT-ORIENTED DATA MODEL FOR MEDICAL IMAGE MANAGEMENT

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A Dynamic Temporal Object-Oriented Data Model for Medical Image Management

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This paper describes the design of a dynamic temporal object-oriented data model that provides a powerful abstraction mechanism for modeling the medical image data in a natural way. It is being developed as part of our efforts to implement an intelligent medical image management system (IMIMS) on top of a picture archive and communication system (PACS)[3] infrastructure. The prototype system can retrieve medical images (e.g. x-rays, computed tomography scans, magnetic resonance scans, etc.) by image features and contents rather than by traditional artificial keys such as patient hospital identification number. Furthermore, solutions to research queries which associate the radiographic findings of an image, the disease pathology, and the categorical patient subpopulation are realized using a knowledge base and the temporal object-oriented data model.

The extension of the traditional object-oriented data model into the temporal domain is an important requirement for accurately representing the data stored in a medical image database. This is because structures in the human body are not static and often change their characteristics and/or existence over time. For example, a database used to build a model of human skeletal maturity involves characterizing the growth patterns of structures in the hand. At birth, only a limited number of bones are present. As we mature, microscopic growth centers **evolve** into new bones. In the wrist area, the eight carpal bones normally appear in roughly four stages. In the fingers, cartilage, the precursor to hard bones, begins to undergo chemical **transformations**. The epiphysis, a structure between the phalange bones of children, begins to **fuse** with the tubular phalange at a certain point in skeletal maturation. Exceptional genetic conditions can cause some bones to undergo a **fission** process, splitting into multiple bones.

The dynamic temporal object-oriented data model we developed uses the traditional object-oriented data model as its departure basis. We enhanced the modeling power of the traditional method by introducing a new set of novel constructs to describe the evolutionary behavior of objects seen in real life. The new model utilizes three types of object constructs:

1. Traditional object constructs[2](see Fig. 1a):
   (a) Aggregation: An object is composed of several constituent objects.
   (b) Generalization/Specialization: Relates an object type to more generic ones and forms an "Is-a" hierarchy. The more generic ones are called supertypes while the more specialized ones are called subtypes.

2. Temporal relation object constructs:

   (a) Object constructs that show the temporal relationship of an object with respect to its universe: The life span of a supertype defines the universe for its member subtypes. Fig. 1b shows the four kinds of relationships between an object and its universe.

   (b) Object constructs that show the temporal relationship between the life span of individual objects within the same universe: Fig. 1c shows the six kinds of temporal relationships between two objects.

3. Evolutionary object constructs(see Fig. 1d):

   (a) Fission: At some time, an object may split into two or more independent objects.

   (b) Evolution: The characteristics of an object may evolve with time.

   (c) Fusion: An object may fuse with different objects to form a new object with different characteristics than either of the constituent objects.

One important contribution of our research is in the modeling of **temporal inheritance** which deals with how time-dependent characteristics of a supertype are inherited by its subtypes. For example, if the first metacarpal bone is in early stage of development (termed TW2 stage C)[4], then it inherits all the characteristics of both its constituent objects, the epiphysis and the unfused tabular bone. When the first metacarpal bone fully matures, it inherits the characteristics of a different object type, the fused tabular bone(Fig. 2). The general rule is that an object may only inherit characteristics from other objects which exist in its own space-time domain. This enables us to answer research queries such as "Retrieve all images for Caucasian females between 6 and 8 years old with the maturity of the distal phalange of the third finger in TW2 stage C".

Another important feature of our data model is its ability to perform cooperative query processing[1]. Solutions to high-level fuzzy queries such as "Retrieve all images for pre-adolescent oriental males with radiographic findings consistent with Turner's syndrome" can be handled by maintaining a knowledge base for imprecise descriptors(e.g. pre-adolescent and Turner's syndrome) and by intelligently using the data model to either relax or restrict the search domain. Image analysis routines which can segment, identify, and characterize various bones and objects in the hand have been developed and are integrated into database search operations.

In this paper, we propose a novel dynamic, temporal data model for representing the evolutionary nature of medical databases. We shall report some of our preliminary experience and effectiveness of this model. This work is part of the collaborating effort among the researchers from the Computer Science and Radiological Sciences departments within our institution. Other aspects of the research including database architecture, the query language, logical indexing, and image analysis algorithms, will be reported elsewhere.

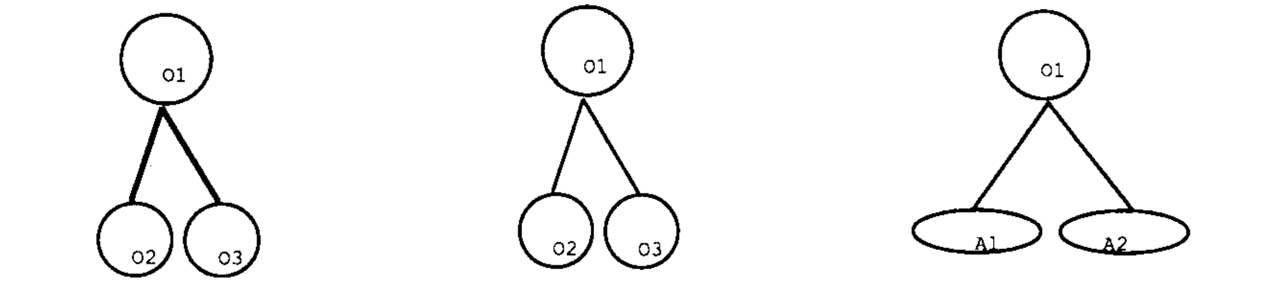
Reference:

1. Chu WW, Chen, Q, and Lee, R, "Cooperative Query Answering via Type Abstraction Hierarchy", in Proceedings of CKBS, October 1990.

2. Hull R and King R, "Semantic Database Modeling: Survey, Applications, and Research Issues", ACM Computing Survey, Vol. 19, No. 3, September 1987.

3. Taira RK and Huang HK, "A Picture Archiving and Communication System Module for Radiology", Computer Methods and Programs in Biomedicine, 30, 1989.

4. Tanner JM, Whitehouse RH, Marshall WA, Healy MJR, Goldstein H., "Assessment of Skeletal Maturity and Prediction of Adult Height (TW2 Method)", Academic Press, London, 1975.



Aggregation: Object O1 consists of O2 and O3.

Gerneralization/Specialization: O1 is a supertype of O2 and O3.

Attributes A1 and A2 of object O1.

Figure 1a: Object Type Hierarchy

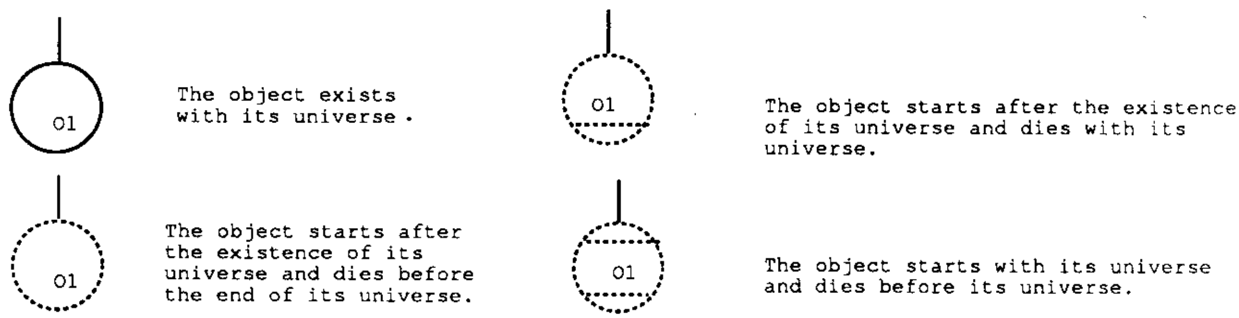


Figure 1b: Temporal relationship of an object with respect to its universe.

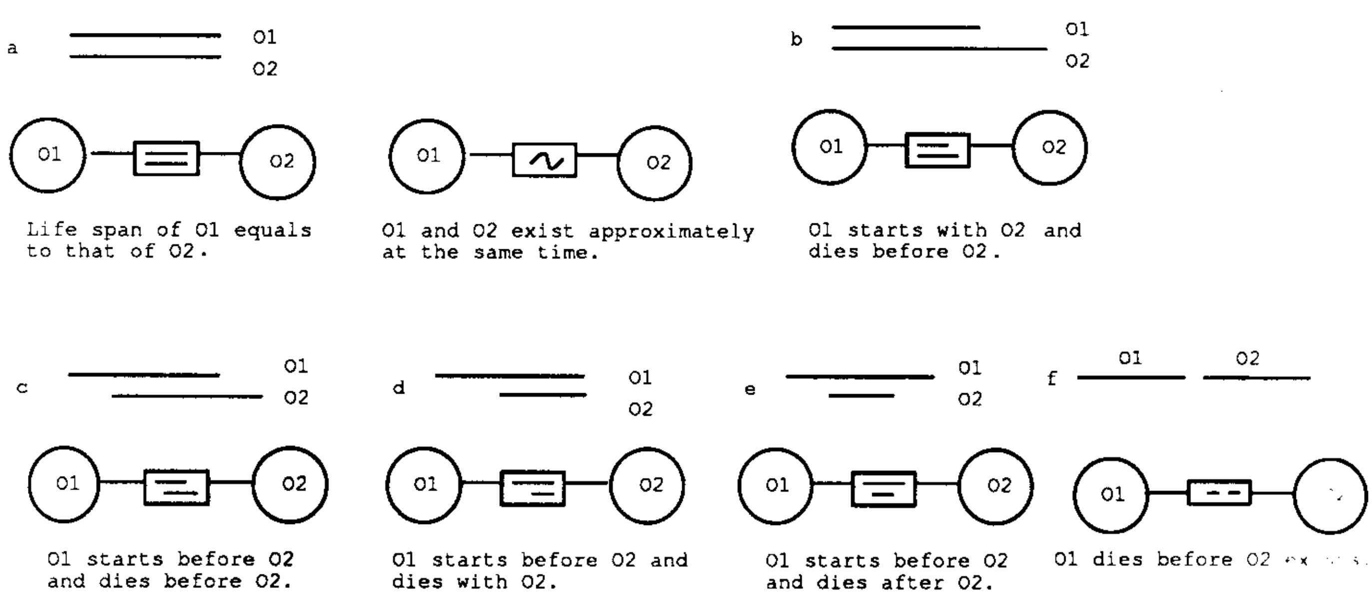
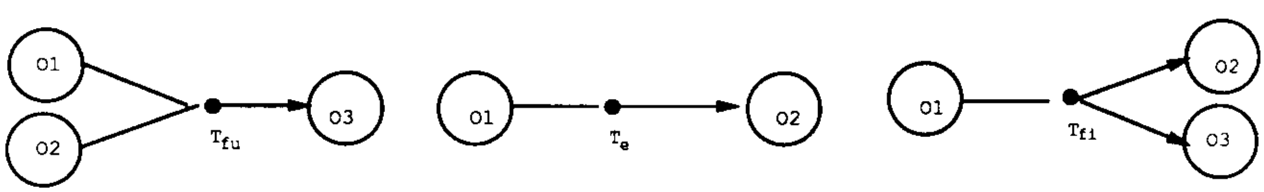


Figure 1c: Temporal relationship between two objects within their universe.



Fusion: O1 and O2 fuse together and become a new ohject O3 at time T_{fu}.

Evolution: O1 evolves into a new object O2 at time T_e.

Fission: O1 splits into two independent objects: O2 and O3 at time T_{fi}.

Figure 1d: Evolutionary object constructs.

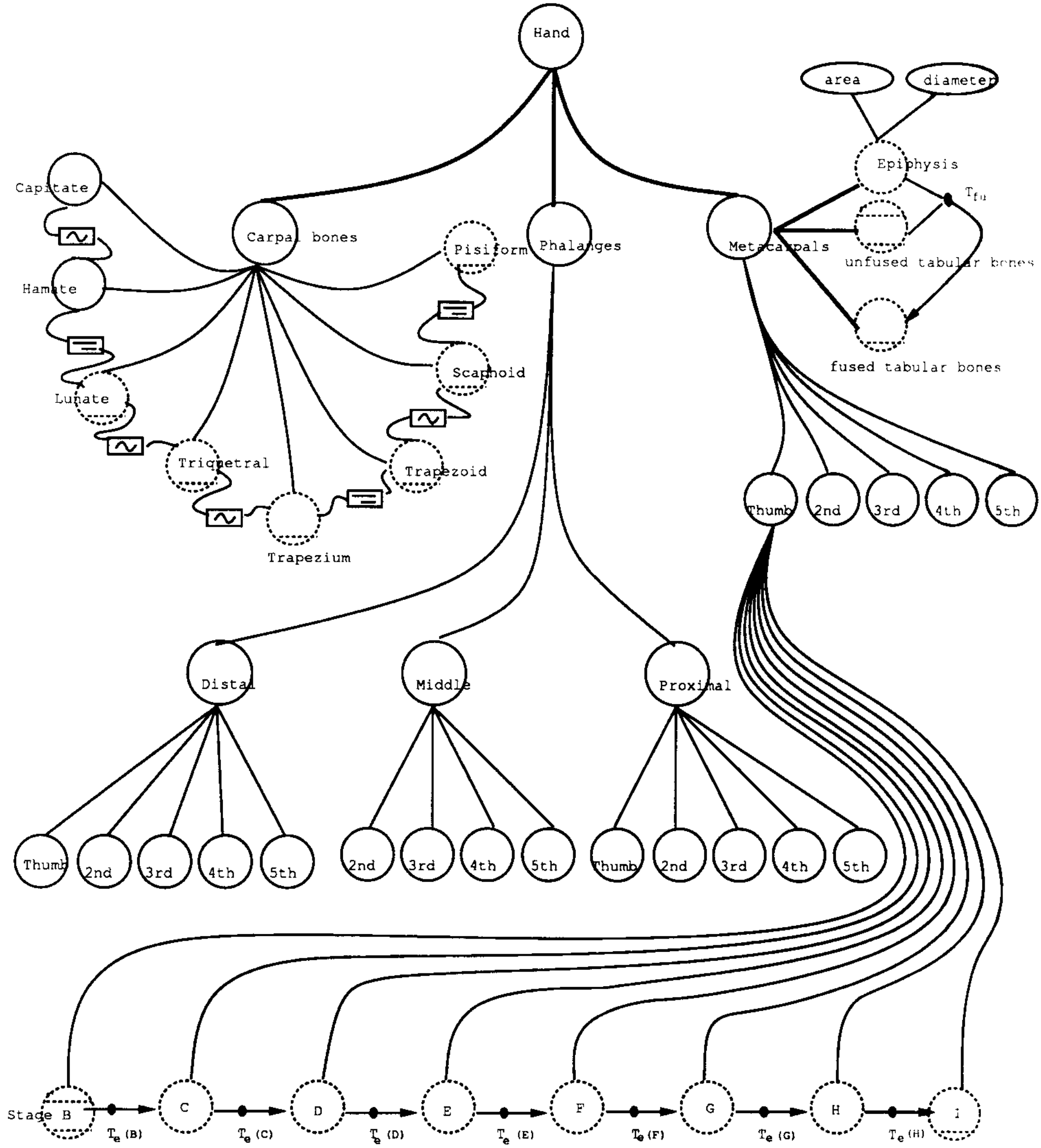


Figure 2: Modeling the growth of a hand with the TW2 method. Not all the details are shown due to space limitation.