A New Face-entity Concept for Modeling Urban Morphology

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Abstract: *The modeling of a common set of urban land features in a topological structure useful for a range of applications, including routine operations and decision-making, is described in this paper. This collection of non-redundant shareable data is based on an identification of administrative agencies that would use and/or manage these data. Using this information, an object-based conceptual model is developed that employs the face-and-entity concept to account for all basic land units and organizes them into different levels of hierarchy. This structuring is based on physical containment (e.g., building and pavement entities are wholly contained in the block entity, resulting in two levels of faces) and urban management rules (i.e., each face and/or its entities are uniquely managed by a certain authority). The derived conceptual model, including both the meta data and the geometry associated with the face hierarchy, is formalized with EXPRESS, an object-oriented data description language that conforms to universal and regional geographical information system (GIS) terminology and standards.*

Introduction

Geographic information management technology is emerging as a powerful means to manage voluminous geographic data, to help cope with the information explosion, and to provide a foundation for problem solving (Antenucci et al. 1991). The application of geographic information system (GIS) technology is no longer restricted to surveyors and map producers, but extends to persons specializing in cadaster, civil engineering, geography, rural and urban planning, utility networks, and other related fields (Burrough 1986). Separately, each application captures essential land information. Inevitably, duplication in data capture occurs that results in inconsistent spatial and currency representations of reality. Resources might be better spent in data manipulation and analyses of shared data. Issues such as data compatibility and sharing, interchange format, and availability are beginning to be addressed, leading to considerable research on data interoperability. However, few GIS organizations, at least in the early stages of GIS implementation, focus on formalizing and standardizing a land feature database serving multiple users.

With an emerging emphasis on urban GIS applications, particularly for management and planning, there is a growing realization that a standardized and semantic database might be valuable. The great variety and multiplicity of functions necessitate common geographically referenced information to facilitate data integration and access among the numerous administrative and planning activities. An optimally designed topographic base data structure is key to achieving such purposes and to avoiding much duplication of technical GIS work and data. This study adopts a holistic approach to the urban environment. Distinctive subsets of the total geographic information of a region are identified and categorized according to their topological relationships and ownership rights. The proposed model also incorporates many of the universally recognized concepts of geoinformation, so that the data structure can be explicitly defined and applied across all urban environments.

Being a compact and competitive society, Hong Kong may be an ideal example to illustrate the requirement of a comprehensive data model. The intensive daily activities encourage a carefully designed GIS model for a complex, dynamic, multidimensional configuration of the urban surface. Like many other cities in the world, this "small and big" city has experience in implementing GIS technology in the context of changing objectives, trial and error, and having to tackle both institutional and technical difficulties, in a decade-long development.

Methodology

A complete database design with good utilization should encompass all four stages of data modeling, ranging from high-level conceptualization to low-level physical constructs. Conceptual modeling is modeling of real-world situations and provides the description of space that is closer to human conceptualization and its semantics. In this study, an understanding of the Hong Kong urban environment and the perception and requirements of land information by various potential GIS users form the primary requisite of the conceptual model. These are collected from documentation and by interviews. Relevant and useful information includes: the routine operations and/or planning process, the spatial unit(s) used, the attributes created by the users themselves and the spatial and non-spatial data required from other departments, the attainment levels of information technology (IT) and GIS, and the problems, expectations, staff training, management, and any future planning in using the technology. The objective is to identify a set of urban map features for different applications. The selected tangible land features and their relationships should be viewed according to their natural setting and management structure, not according to the form of symbolization as appears on maps. In fact, even with traditional map use, the analyst should not relate map information as mere lines, pictures, or symbols, but according to what is perceived in the actual environment under the setting of a particular application. Such flexibility of allowing and maintaining varying perceptions of mapped information to that of the real world is and should be the primary concern of any modeling of land features (Pun-Cheng and Parker 1996). In the process of capturing data in digital form, the way that it is structured systematically is important in configuring a user's perception and an analysis needs of the data. Thus, in capturing urban land features into series of lines and points or arrays of pixels, it is necessary to specify explicitly how the features are arranged in relation to one another, in much the same way as the interaction of the complex spatial features function in the real world.

Using this approach, a concept is developed via an object-oriented perspective. The intuitive appeal of object orientation is that it provides improved concepts and tools with which to model and represent the real world as closely as possible (Khoshafian and Abnous 1995). The object-oriented approach is important in that it has been widely accepted as appropriate to modeling complex data structures and hierarchically organized knowledge domains; in the case of GIS, it captures more semantics than do existing data models (Car 1997).

There are two main categories of object classes. The first category deals with the urban land features that are modeled into "entity" and "face." The identification of a land feature type having unique characteristics or independent significance of its own is called an "entity." Indivisibility into like units is based on the properties used in the definition, and there is not a necessary implication of complete homogeneity within the spatial extent of the entity (Laurini and Thompson 1992). It can be "real" and existing independently or "virtual" which is derived from the former (Feuchtwanger 1993). An "entity instance" will be a member or an occurrence of the entity-like buildings and a building named "Hutchinson House." Instances may be differentiated solely on the basis of a non-spatial attribute value or for a combination of characteristics. The "entity" and "face" concepts identified in this study, in fact, correspond to "object identity" and "object classes" in object-oriented terms. From these, users may generalize, aggregate, or associate land features in ways and scales based on their attached attributes according to their own application needs. For instance, the pavement entity, the building entity, and/or the park entity can be aggregated into a semantically higher level object called the "block face." By inheritance, attributes of the block face, such as geo-referencing codes or address, are made applicable to its component entities (or "objects"). This structuring is based on both the physical containment (e.g., *building* and *pavement entities* are wholly contained within the *block entity,* resulting in two levels of *faces*) and urban management rules (i.e., each face and/or its entities are uniquely managed by a certain authority).

The second category of object classes is concerned with the spatial forms of the first category. By modeling these geometric and topological spatial objects as individual objects in an object-oriented approach, the relationships between their primitives (such as node, edge, and face) are more explicitly defined, especially with regard to inheritance between classes. For example, a top-down hierarchy is formed between the geometric object, geometric primitive, topological primitive, and node, edge, and face (of the same level). Hence, the attributes of position and the geographic identifier can be inherited from the geometric object all the way to the primitives such as node. A more detailed explanation of the conceptual model is given in the section titled "Modeling the Spatial Complexes of Urban Hong Kong."

As already implied, the hierarchy theory is also applied to spatial systems described here. A hierarchical structure is made up of different levels. High and low levels may correspond to superclass and subclass concepts of inheritance in object-oriented modeling. In other words, attributes of high-level components may develop into low-level ones. Hierarchy development facilitates the modeling of some object-oriented constructs such as generalization and aggregation. In addition, it has the advantages of reducing processing time upon data retrieval and manipulation as well as maintaining the stability of a system. As summarized by Car (1997), the three properties of hierarchies–part-whole, "Janus-effect," and near decomposability-can also be applied to the structuring of an urban system. Considering the first property, a street may be viewed as a whole with adjoining street segments as its parts, a block as a whole nested by various land-use types as its parts, and, in turn, an administrative district as a whole with streets and blocks as its parts. The role of whole and part changes from one level to another. Extraction of the whole and/or parts of a level varies the user's ways of manipulating and analyzing urban information. The different ways of viewing a feature as whole or part is referred to as the Janus-effect. In addition, the nesting of smaller areas into a larger area (e.g., a district is nested by streets and blocks which in turn are nested by street segments, buildings, etc.) indicates the property of near decomposability. In this study, the terms "spatial complex," "face," and "entity" are used to mean "level," "whole," and "part" in the concepts of hierarchy. Further elaboration of face hierarchy is found in the section entitled "Concept of Face Hierarchy."

As the hierarchy concept here is built from more specific application-based (for urban management) knowledge or rules other than mere spatial information, the relation between the different levels is considered as being "semantic." However, the rules or criteria that build up these semantics may not correspond to the spatial hierarchy that contains them. For instance, spatially, a flyover is located within certain parts of a road (enclosed topologically), but they may occupy the same hierarchical level under the domain of transport network or type of road surface.

Since formalization of conceptual models of space is essential for their implementation, the face-entity conceptual model being formed must be written in a language commonly understood, meaning that the GIS terms and definitions used are as widely standardized as possible. With the formalization process, the conceptual model, while being physically independent (hardware and software), may be implemented in a wider range of GIS packages. In turn, it also facilitates the design and implementation of the existing software and increases its efficiency (Car 1997). In this aspect, EXPRESS, a model description language developed for the International Organization for Standardization (ISO) Technical Committee 211 – Geographic Information/Geomatics, is used. It is an object-oriented data description language that is able to formalize well the corresponding semantic concepts of the face-entity model.

Before discussing the data model in length, it is essential to explicitly define terminology and concepts related to spatial data modeling. Some forms of universal agreement or standardization are preferable, so that the model can be applied in a wider context. Terms defined in the Appendix A are also explained in publications of the ISO (1996) and ISO 15046-4 (European Committee for Standardization 1995).

Selection of Entities

In this study, features selected as distinct entities generally have two properties: they are administratively definable, and they are uniquely manageable. The delineation of an entity (or an object in an object-oriented context) is a compromise between a general understanding of the land-use type and its controlling body as laid down in cadastral records. Since large-scale topographic maps form the major data source, some degree of grouping the discrete map elements (symbols or primitives) into an "elementary entity" is required. As examined from the range of urban functions among various managing bodies, the manageable units in the data model are defined as below:

Manageable Unit	Managing Body
private building	Buildings Dept.
government building	Architectural Services Dept.
public housing	Housing Authority
open space	Urban Services Dept.
vacant land	Land Administration Office
pedestrian ways	Highway Dept.
vehicular ways	Highway Dept.
utility point	various utility companies

The list may not exhaust all the land-use types, but it covers the entire urban surface in a continuum. Basically, the entire urban ground surface is occupied by discrete patches of land uses. It is essential to identify an area with an agreed-upon unique type. Unlike modeling of natural landscape, there should be no areas of confusion or uncertainty regarding transitional, mixed, or "gray" areas. Hence in this case, each building clearly belongs to one and only one of the three categories — private, government, or public housing. Likewise, non-built-up areas on the ground surface are either open space for public recreational purpose (parks, gardens, or sitting areas) or vacant land awaiting future development or an approved type of land use. On the other hand, public access of pedestrian and vehicular ways is separately considered. Although they are managed by the same department, their networking and applications can be very different.

Entities described in other applications may be associated with one or more of these elementary entity groups. For instance, private gardens or resting areas such as podiums belong to parts of a building, and an underground shopping center just beneath a road is linked with a building or a road on the surface. This also applies to utility features that are found completely within pavement. Above all, the key for selection of these basic entity groups lies in their being uniquely and exclusively controlled under one managing party. So it is totally case-specific and is likely to be different for another city with dissimilar administrative divisions. The advantage is that any spatial edit due to redevelopment or planning minimizes the number of parties concerned. These elementary entity groups occupy the finest resolution, and, therefore, the lowest hierarchy of the urban feature data model. Any insertion, deletion, or modification of an existing or new entity type must obey the universal law of a continuous surface of zero overlaps and gaps, which is described in later sections.

Concept of Face Hierarchy

The model employs the face concept in that the urban surface consists of a series of object-defined (e.g., a building or a road) or arbitrarily defined (e.g., a district) two-dimensional topological primitives. In other words, an entity-like building or open space is modeled as a face, an elementary face. The total of elementary faces forms a larger face (a district). Each face of a hierarchical level can be useful in one application or another. Hence, a face may consist of one or more entities or objects. Planar graph faces of the urban data model obey two rules (Figure 1):

(a) in the face hierarchical structure, faces of a lower level exhaustively cover that of the preceding higher one, so that no overlap or gap in between faces would occur;
(b) the universal face is exhaustively covered by a nesting of faces.

Such a data structure facilitates the merging of attributes, value-adding, and data maintenance. In another perspective, these

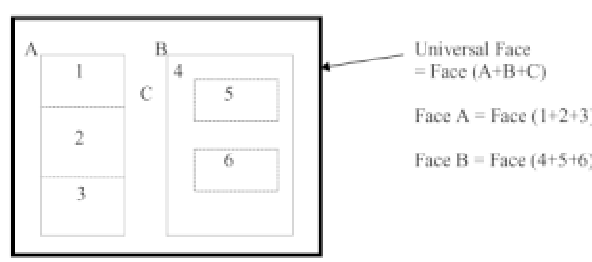

Figure 1. A hierarchy of faces nesting into one another. Faces of different hierarchical levels are shown in different face boundary line patterns.

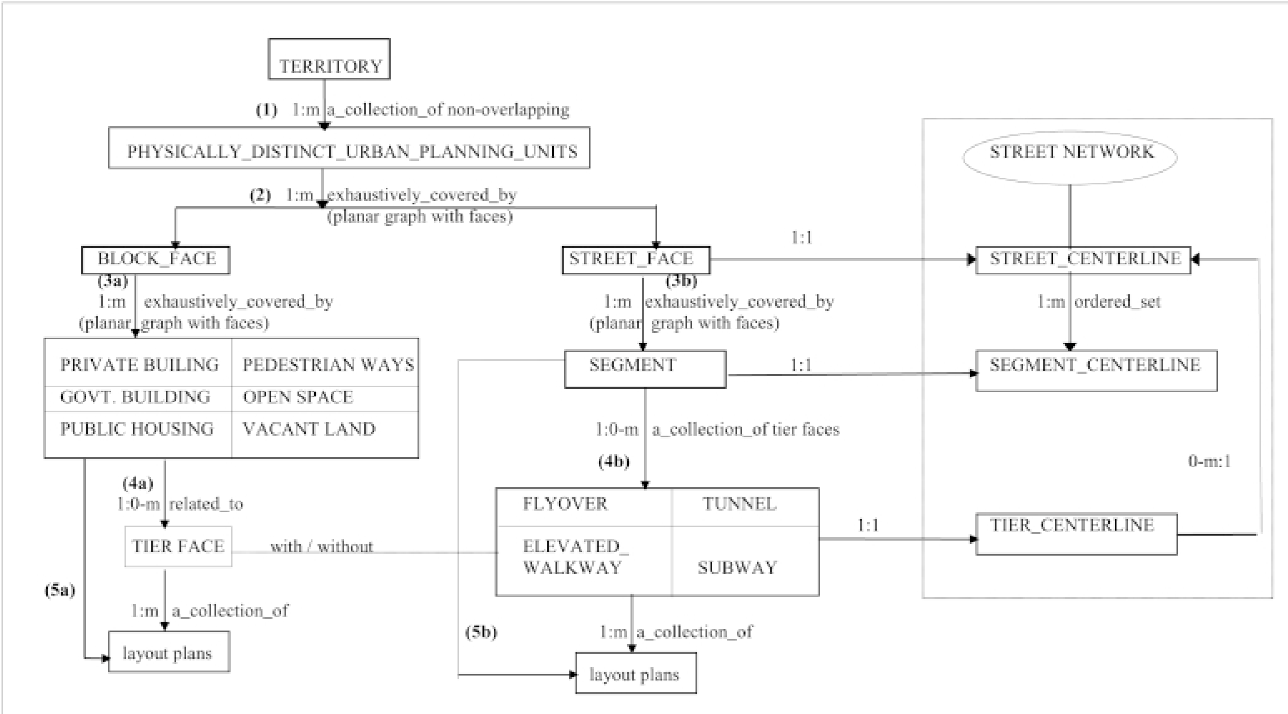

Figure 2. The face hierarchy of urban Hong Kong; spatial complex of hierarchical level 1.

faces constitute a spatial complex in which entities are related to each other in a well-defined geometry and topology. Figure 2 has defined a face hierarchy for the urban structure of Hong Kong. Each hierarchical level is a collection of entities that makes up a spatial complex instance. The sections below give a hierarchical view of different faces and explain how they are organized into spatial complexes of successive orders.

Modeling the Spatial Complexes of Urban Hong Kong

Level 1 Spatial Complex: The Universal Face

Based on the notion that the application schema is to provide basic urban land features to multiple users, the universal face would be all of the urban surfaces of the entire territory. At the highest level of the spatial complex (Figure 3), the entire territory consists of several non-overlapping urban complexes or planning units (which may be adjoining or separated). These are delineated either by a distinct physical barrier such as a hill or harbor and/or a relatively static and long-recognized broad administrative boundary. In the latter, the boundary is a street or part of a street. In other words, a street face or part of it may be shared by two adjacent planning units.

Level 2 Spatial Complex: The Street-Block Face

In the next level, each physically distinct planning unit contains a collection of planar graph faces of blocks and streets exhausting the surface (Figure 4). Geometrically, the block face and street face share the same spaghetti boundary, so that no sliver boundaries, overlapping, or gaps should occur. The line-entity relation is one to many (1:m). Topologically, the block and street faces are non-overlapping and wholly contained (except those parts of

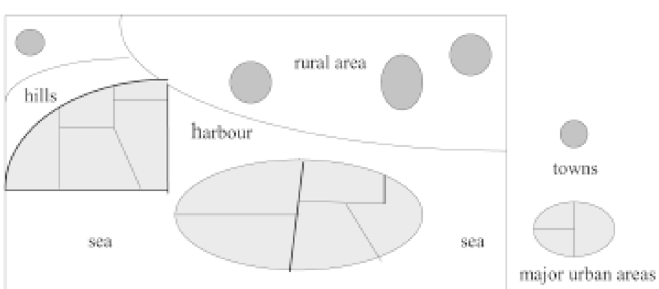

Figure 3. The universal face of urban complexes.

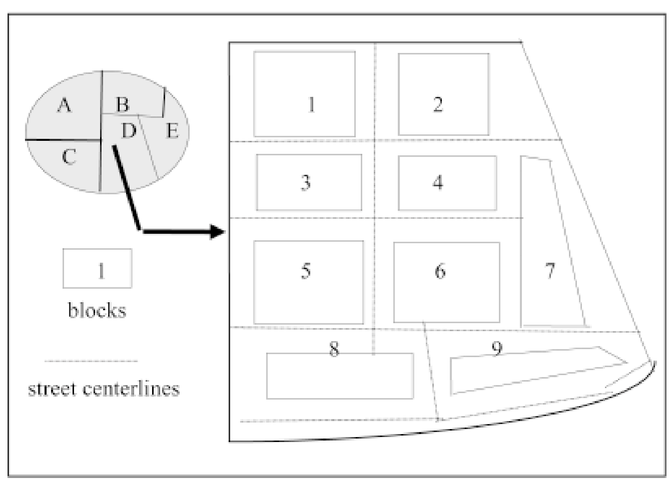

Figure 4. The street-block face.

a street that are bounding between two adjacent planning units) in the physically distinct urban planning face. For example in the figure, "D" represents an administratively defined planning unit that consists of nine blocks and adjacent streets exhausting its planar surface. Users may extract information of all roads surrounding any block, while the block information may also be summarized for a particular stretch of road.

Moreover, certainly for a seamless data structure, such information retrieval may extend beyond adjacent planning units if the same street continues. Cross-referencing between blocks and roads allows planning at a strategic or territorial level and is especially useful for land-use and transport planning.

It is generally agreed that the street-block face, as delineated from a physically or administratively distinct planning unit, is useful for urban administration such as collection of census data, voting, and police patrol zoning. However, other applications such as transport networking or routing would require the modeling of streets to be extended beyond adjacent units. To cater to such requirements, the modeling of streets as edges rather than faces is more desirable. With the philosophy that centerlines are generated from each street face, logical consistency should be maintained (i.e., a centerline should wholly and exclusively be contained within a street). Its connected nodes should coincide with the two bounding edges of the street. It should neither extend into any block face nor be disjunctive with adjacent centerlines. The summation of centerlines would form a complete street network of the entire territory.

Level 3 Spatial Complex

The Block Face. When going down to the spatial complex of a lower hierarchical level, a higher degree of resolution or detail will be represented. The block face now wholly contains a number of entities (e.g., a private building, government building, public housing, pedestrian ways, open space, or vacant land), with each being another smaller face on its own (Figure 5). Like its higher level counterpart, geometrically, these entities share the same spaghetti boundary with adjacent ones. No slivering, overlapping, or gap of any kind should occur. Any attempt to change the boundary of one entity should consider its effect on adjacent ones. Topologically, each entity is referenced by the types of adjacent entities as line-entity relations are 1:m. For example, a building can be adjacent to another building, a park, or the pavement (pedestrian way). Such examination of immediate neighborhood conditions is, in fact, socioeconomic information that is valuable for urban management and planning, especially those concerning cadastral rights, fire, and structural safety.

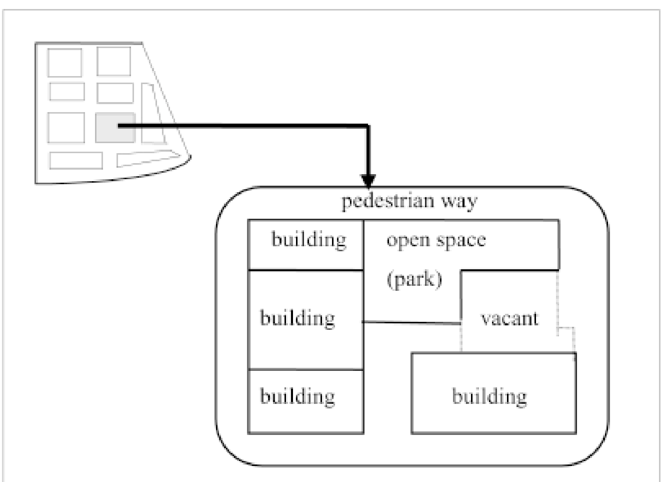

Figure 5. Entities within a block face.

The Street Face. The street face, on the other hand, is exhaustively covered by faces of street segments (Figure 6). A street is defined as a longitudinal area of vehicular way with each face being uniquely identified with a name (e.g., A, B, or C). Each segment is a subdivision of the entire stretch of a street (e.g., B1 or B2). Geometrically, the segment polygon is longitudinal in shape, its lengthy sides share the same boundaries with the block face, while the two ends are added, and the dark edges denote separation from other street segments. Segmentation is performed according to the following rules:

(a) where a segment boundary marks the end of a street, the dark edge is an edge joining two opposite blocks (e.g., segment E1 ending at street A and segment E2 at street C); and
(b) where two dark edges joining diagonally opposite blocks cross each other, a new connected node (defined as a "dark node") is created, marking the junction of two or more stretches of streets, each with its adjoining segments.

From the dark edge and dark node information, it is possible to determine the topological relationships between street segments. In applications such as transport planning or utility management, it is extremely useful to model a street with different segments, each being perhaps different in the number of lanes, direction of travel, traffic facilities, etc.

As segments are divisions from a street, the same applies to segment centerlines from a street centerline. Topologically, connected nodes of segment centerlines should be consistent with the connected nodes at the two ends of the segment face (Figure 7), meaning that each street centerline is an ordered collection of segment centerlines.

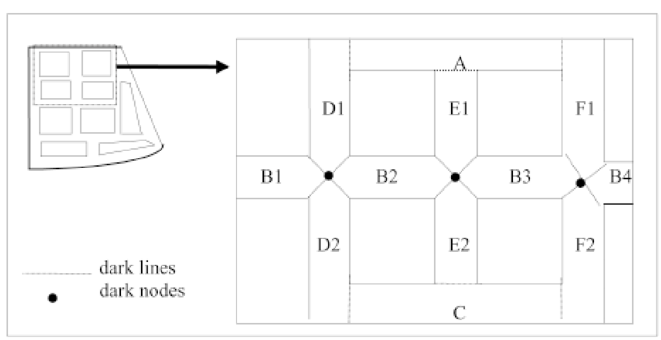

Figure 6. Planar graph faces of street segments.

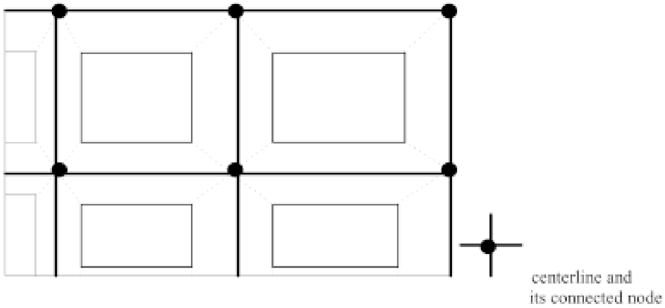

Figure 7. Relationship between centerlines and segments topology its connected node.

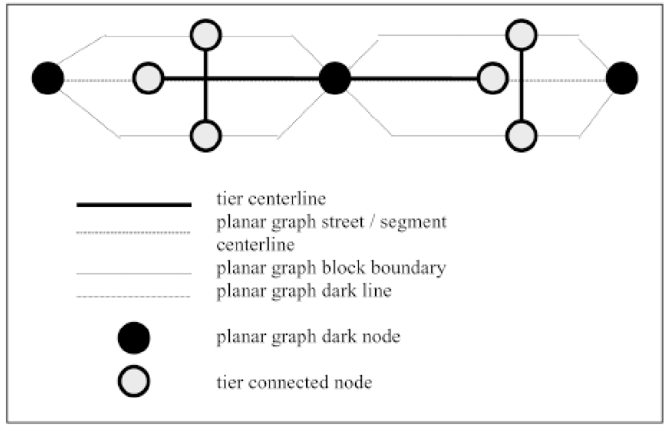

Figure 8. Tier centerlines and planar graph centerlines.

Level 4 Spatial Complex

The Tier Face of Block Entities. Cities are characterized by intricate horizontal and vertical components. The tier level is represented in the fourth hierarchical level. The tier level is defined here as a face not belonging to the ground level. In order to exist on its own, it should be related to at least one ground level face or entity. Therefore, each entity in the third level may or may not be associated with its tiers to form another spatial complex. Entity-tier relations are 1:0-m. A piece of vacant land may not be associated with any other structure above or below it. Where tiers occur, certain rules are needed to explicitly define their relationships. For instance, the tier faces (which may be stories or a podium) of a building should overlap the planar graph building face at the ground surface vertically at an overriding percentage. Tier faces consist of entities that may be the same as or different from those of associated planar graph faces. Hence, a park (belonging to an entity group of open space) may be associated with a subway (belonging to an entity group of pedestrian ways) beneath it.

The Tier Face of Street Segments. Like the block face, at a lower hierarchical level, each segment face may or may not be related to a tier level directly above or below it. These tier faces are of entity types: flyover and tunnel (entity group of vehicular ways) and elevated walkway and subway (an entity group of pedestrian ways), all of which intersect vertically with the planar graph street and segment faces. If these occur across a block face, they are considered as tier levels of block face entities. Here, these faces are wholly contained and so are uniquely identified with the segment face(s) to which they belong.

As these tier entities form an integral part of the transport network of the entire urban area, it is essential to model these as centerlines like those of planar graph streets and segments. Without this, connectivity between different routes will be seriously affected. These kinds of configuration of vehicular and pedestrian ways are incorporated into the model with a view that the demand for such information has been increasing. In doing so, tier centerlines are created and should be connected and referenced to the planar graph of the street or segment centerlines to form a complete street network of the universal face (Figure 8). For vehicular ways, each segment centerline is connected to zero or more than one tier centerline via a tier-connected node at either end. For pedestrian ways, the connected nodes of tier centerlines intersect at the street/block boundary, so that it would connect to a planar graph pedestrian way.

Level 5 Spatial Complex: Layout Plans

At the lowest level of the base data set, users may attach their detailed layout plans (e.g., floor plans of different stories or a landscape design of a park) to these ground level faces or tier level faces. These need not be part of the central data set, and an individual owner can retrieve and edit such information from selected faces without affecting the overall topology of the entire spatial complex.

In summary, when organizing features into different faces, two aspects of data change are taken into consideration. First, at the highest hierarchical level, the universal face is best composed of relatively static face boundary units. Permission to edit boundaries by any government department should not be allowed in the universal face. The possibility of spatial change is slight for the street-block face but increases when going down to layout plans. For instance, it is anticipated that the buildings and open spaces will have more frequent demolitions and constructions, when compared to the block and street faces higher in the hierarchy. Spatial updates at the smaller faces would involve minimum retrieval of data and least affect the overall topology. Second, when considering permission to update non-spatial information associated with an entity, subdivision into more discrete faces is preferable. Raw data of diversified sources may be aggregated differently to cater to the requirements of various applications.

Geo-Referencing

In the face data structure, a consistent and familiar referencing system is required to link up the different hierarchical levels. An indirect position as described by a widely adopted geographic identifier might be used. At the highest level, codes from the tertiary planning unit (TPU) can be used to denote a clear separation of various physically or administratively distinct urban complexes. The TPU has long been adopted by the Planning Department and the Census and Statistics Department as the basis for planning divisions and demographic data collection. Hence, these are meaningful and manageable units for aggregating variables useful for strategic and regional planning. Moreover, the TPU divisions are well related to district delineation, in which users can retrieve faces according to the familiar district names (Figure 9). In the second level, each TPU is a collection of blocks with unique block numbers from 01 to n (Figure 4). The block number together with the TPU code that it belongs to would identify the block (by the block code) as a unique feature in the spatial complex.

Streets are referenced by a unique code linked to a name (Figure 10). Street segments abutting a block are coded with both the block code and the street code, so that location information regarding a street (name, blocks, and districts passed through) can be conveniently retrieved. Streets that bound a TPU are also easily identified with two different block codes. On the other hand, faces or entities inside the block, such as buildings and parks, are labeled first by their entity-type codes (Figure 11); each is then associated with a name (if any) and address. Note that all private buildings, government buildings, and public housings are captured under a single code. This minimizes the efforts during data capture in making such differentiation.

In addition, one may not be able to determine the type of a building from conventional maps (an important data source). However, this may be remedied later when different managing bodies are granted rights to attach their own attributes to these spatial data. Entities sharing the same boundary may also reference these codes, so that information on the immediately surrounding neighborhood can be obtained. Editing of entities and versioning are important if special attention is to be paid to the legal aspects of extending beyond the adjacent piece of land. On the other hand, the address of an entity is comprised of a street name and number. Therefore, apart from the conventional GIS capability of extracting TPU and block number information through point-in-polygon or polygon-in-polygon searches, it allows merging of information across the faces of different hierarchical levels.

TPU	DISTRICT
111-112	West
113-115	Sheung Wan
116	West
121-124	Central
131-135	Wanchai
140-143	Mid-levels
144-149	Tai Hang
151-157	North Point & Quarry Bay
161-165	Shau Kei Wan & Chai Wan
171-172	Pok Fu Lam
173-176	Aberdeen
181-184	Peak
190, 192-198	South
191, 199	Aberdeen

Figure 9. Tertiary planning unit codes of Hong Kong Island, Hong Kong.

STREETCODE	NAME
1011	KIN SAU LANE
105	CAINE ROAD
1186	LAN KWAI FONG
1379	MAN ON STREET
1409	MEE LUN STREET
1567	OLD BAILEY STREET

Figure 10. Examples of street codes and names.

TYPE	DESCRIPTION
0	pavement / pedestrian ways
100	buildings
200	vacant land, works in progress
300	park. garden, sitting-out areas

Figure 11. Entity-type codes.

Considering the tier levels, it is generally agreed that those of pedestrian and vehicular ways are of wider interest than those of other entity types. So tier-level information will be limited to elevated walkways, subways, flyovers, and tunnels, as coded in Figure 12. These represent the tier centerlines in which connected nodes would link up with either segment centerlines (for vehicular ways) or block boundaries (for pedestrian ways). Figure 13 summarizes the relationship of different code search directions. The geo-referencing system mentioned has taken into consideration both the conventional practice of address matching during data capture and the familiarity of general users.

The various coding systems of the master data set mentioned above allows flexible association with coding or zoning of most urban applications. For instance, templates of a conventional map index, police patrol zones, district board electoral divisions, etc., may overlay with the source map data set. Partitioning of a continuous or seamless data set is made more semantic. Information may be retrieved and summarized for the specific zoning, as required by the users. In addition, it is advisable to keep files of different codes separately. In this way, any updating of naming conventions (a fairly frequent occurrence in Hong Kong) need not be performed across all hierarchies of the whole data set. This means that for all existing land, various codes remain unchanged while a change in name (e.g., for a building or a street) is updated only in one central core data file.

LEVEL	DESCRIPTION
0	street at ground level
1	flyovers or elevated walkways
-1	tunnels or subways

Figure 12. Tier-level codes.

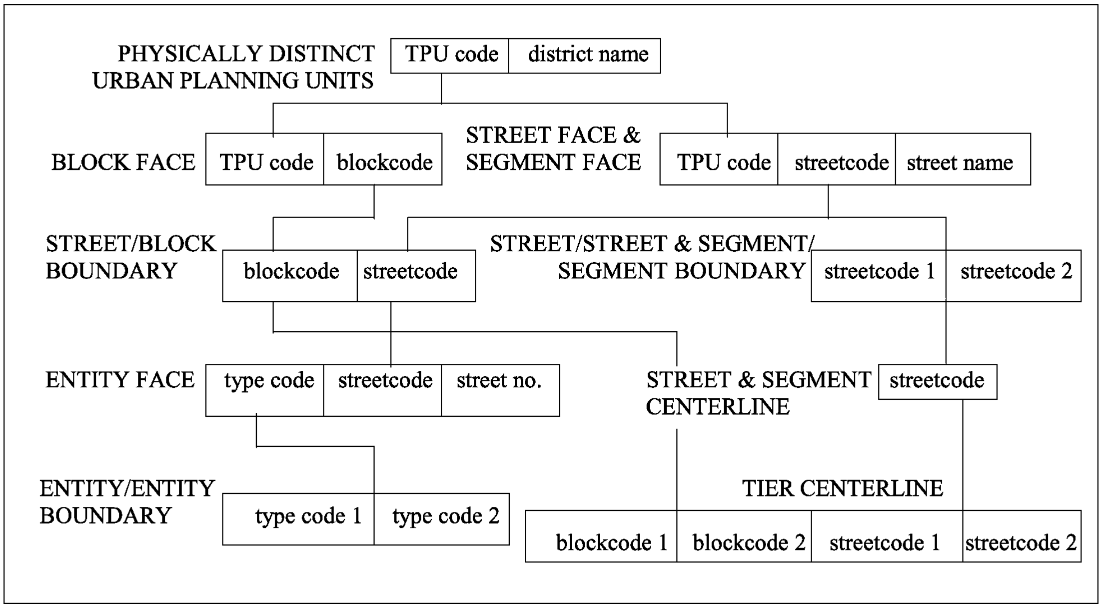

Figure 13. Geo-referencing codes of faces/centerlines in different hierarchical levels.
Adjoining lines in between the codes indicate search directions that may cross several levels.

Formalization

Formal models provide a simplified, concise, and consistent description of real-world phenomena using mathematical or logical axioms and principles (Mark and Frank 1996). The formalization method introduced here uses an object-oriented data description language, EXPRESS, which conforms well to the object-oriented approach in the previous stages of modeling the urban environment. Every model is represented in EXPRESS as a schema. Objects are represented as entities and described using attributes. Three separate schemas (see more in Appendix B) are written for this application.

The Meta Data Schema essentially covers definitions of all core data files as described in the section entitled "Geo-referencing." All absolute positions and indirect geo-codings are put under one schema. In this way, non-spatial information is distinguished more clearly and may be edited by only one authority or coordinator. In addition, the information can be accessed or referenced by other application schemas with the changes being stand-alone.

Next, the Planar Spatial Base Schema describes the spatial data structure of geographic features in its planar graph setting. A diagrammatical explanation of the relationships between different geometrical entities is given in Figure 14. It shows that geometric primitives and topological primitives are no longer treated separately. Instead, topological primitives are subtypes of geometric primitives. Once topology is included to describe geographic features, geometric objects (including geometric primitives) cannot be defined independently of each other. They must be defined and used in the context of a specific schema, as members of a specific geometric complex. A geometric complex is an integrated set of geometric objects that conforms to a specific spatial schema. In this case, the selection conforms to the planar urban surface configuration. The complex is subject to planar constraints. It includes two-dimensional geometric objects. The geometric primitives are mutually exclusive and exhaust the plane (i.e., every point in the plane is on one and only one geometric primitive).

Lastly, the Urban Complex Schema is the core schema of the base data supply. The sequence follows that of the hierarchical levels of spatial complexes. Other more specific applications using the urban land information may have a different schema in terms of entity types, attributes, specialization and generalization, and their cardinal relationships. However, like this central database schema, they must all be referenced to the same Meta Data Schema and the Planar Spatial Base Schema.

Conclusion

This paper has suggested a new explanation of the "face" concept and its relations to "entity" to model the complex urban land configuration for multiple applications. It points out that faces are related to each other both geometrically and topologically within the same or between spatial complexes of various hierar-

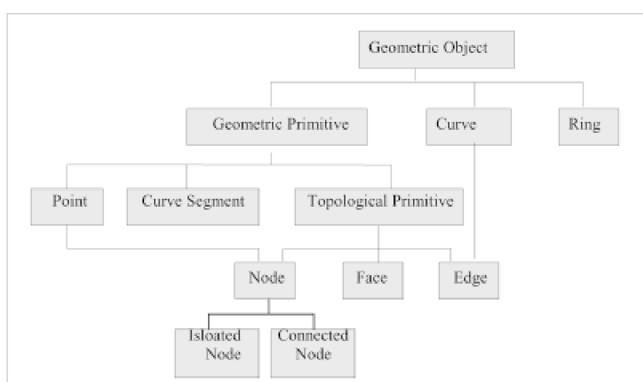

Figure 14. A schematic diagram showing the planar spatial schema.

chical levels. The exclusive containment of faces between successive hierarchical levels enables information integration and distinct management among different user groups. Although structuring of faces varies according to governmental and institutional operations of land data of individual nations or cities, the fundamental concept of non-overlapping faces may be universally applied. Features or entities may be grouped and nested into faces of different hierarchical levels, from which other forms of representation may be performed. In summary, the derived model has satisfied both the technical and the organizational issues. Technically, it is geometrically and topologically consistent across all levels of applications. Not only is it semantically understood by general users, but it is also well conformed to universal and regional GIS standards. Organizationally, the model facilitates spatial and non-spatial edits performed by different authorized bodies, data exchange, and distribution among users, while limiting duplication and multi-versioning of these tasks.

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Acknowledgments

The author would like to gratefully acknowledge the Commonwealth Academic Staff Awards Scholarship and the Hong Kong Polytechnic University for the funding of this research project. Thanks are also given to the Survey and Mapping Office, Lands Dept., HK SAR Government for the release of digital map data.

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Appendix A

Entity — a real-world phenomenon that is not subdivided into phenomenon of the same kind (alias: **feature**) (e.g., a park, a road segment).

Geometry — a digital/geometric representation of all parts of an entity, which can be a point, curve, or surface.

Topology — the relative position/connectivity of a feature; its spatial position may be described by a set of geometry configurations.

Attribute — a defined characteristic/non-spatial element of an entity (e.g., building age).

Point — a 0-dimensional object that specifies geometric location; a set of coordinates (x, y) that specifies the location.

Node — a 0-dimensional object that specifies topological locations; a set of coordinates (x, y) that specifies the location; a node is a point, but a point may not be a node.

Dark Node — an imaginary 0-dimensional object that is created from intersections of two or more dark edges; a set of coordinates (x, y) that specifies the location.

Isolated Node — a node not related to any edge within a topological complex (e.g., a fire hydrant is represented as an isolated node).

Connected Node — a node that terminates one or more edges.

Label Point — a point within an area carrying attribute information about that area.

Curve — a one-dimensional geometric object that edges up 2 or more points (alias: **line**).

Edge — a one-dimensional topological curve or object that connects two nodes (alias: **link**).

Dark Edge — an imaginary (not depicted physically on land surface) one-dimensional topological curve or object that edges up 2 or more points.

Face — an arbitrarily defined two-dimensional topological primitive bounded by one or more curves; a face may consist of one or more entities (alias: **polygon**).

Universal Face — a face containing all of the area within a geometric complex that is not contained within other faces. *Note:* the universal face differs from other faces in the geometric complex in that its outer boundary may not be explicitly described; it is assumed to be the outer boundary of the data set in which the geometric complex occurs.

Spatial Complex — a collection of spatial objects related to each other in a well-defined way, consisting of both the geometric complex and its subtypes, topological primitives.

Geometric Complex — a collection of geometric objects (primitives or composites), the elements of which are topologically related to each other in conformance to a specified spatial schema.

Geometric Object — a geometric primitive or a geometric collection treated as a single entity (i.e., the spatial representation of an object such as a feature or a significant part of a feature).

Topological Primitive — a subtype of a geometric primitive that represents information regarding topological properties.

Topological Property — property of spatial configuration remaining invariant under continuous transformation.

Chain Node Graph — a topological complex consisting of nodes and edges.

Planar Graph — a chain node graph geometrically realizable on a one-dimensional plane in which all intersections are at nodes.

Planar Graph with Faces — a topological complex consisting of a planar graph and a collection of faces that correspond to the contiguous areas within the planar realization of the graph.

Application Schema — a conceptual schema for a certain application; it integrates elements from other conceptual schemas, each of which defines standard ways of describing a specific aspect of geographic information.

Spatial Schema — provides the structures that may be used for representing the spatial characteristics of features within an application schema.

Appendix B

Appendix B is the formalization of the urban land information model of Hong Kong in EXPRESS, a data description language developed by ISO. Three schemas are written, namely the Meta Data Schema, the Planar Spatial Base Schema and the Urban Complex Schema describing the definitions of all core data files, the spatial data structure of geographic features and the different hierarchical levels of spatial complexes respectively. All schemas show that they are referenced to one another. These schemas may be viewed in their entirety at **http://www.urisa.org/journal/accepted/pun-cheng.htm.**