FUNCTIONAL REQUIREMENTS FOR A COMPREHENSIVE TRANSPORTATION LOCATION REFERENCING SYSTEM

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PRESENTATION OUTLINE

- Introduction
- NCHRP 20-27(3)
- Definitions
- Functional Requirements
- Conclusions

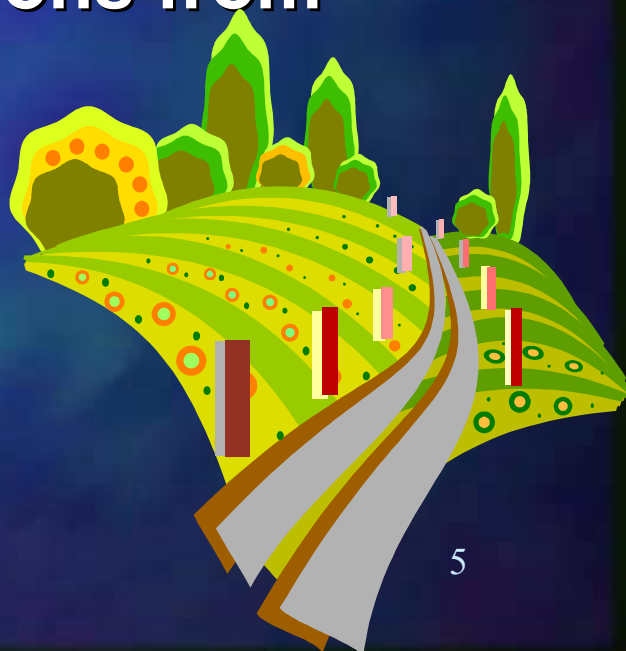
Introduction

INTRODUCTION

- Changing role of Transportation Agencies
- New spatial technologies
- Transportation Agencies manage and share multi-dimensional data
- No framework
  - to integrate data across dimensions and referencing systems
  - to use multi-dimensional data effectively

COMPREHENSIVE TRANSPORTATION LRS

- Represents objects / events as they occur in real world
- Enterprise-wide
- Facilitate the representation of business functions/processes/applications from local level to federal level
- Time-based analyses: Historical Trends, Prediction, Identification, Generalization



COMPREHENSIVE TRANSPORTATION LRS

Key element in developing a comprehensive transportation LRS is to specify what it is intended to do (i.e. functional requirements).

FUNCTIONAL REQUIREMENT

A functional-level capability or business rule which is necessary to solve a problem or achieve an objective (after Martin 1990).

NCHRP 20-27(3)

NCHRP 20-27(3) RESEARCH TEAM

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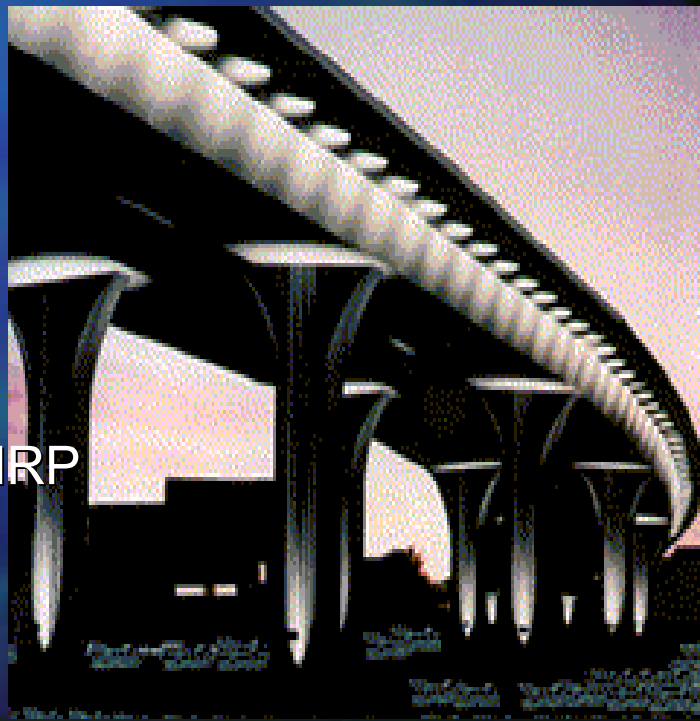


OBJECTIVES OF NCHRP 20-27(3)

- **Establish community consensus on the functional requirements for a Comprehensive Transportation Location Referencing System (LRS) data model for multi-modal transportation systems.**
- Develop an LRS data model that meets the functional requirements.
- Develop guidelines for implementing LRS data model at transportation organizations.

NCHRP 20-27(3) WORKSHOP OBJECTIVES

Identify / define functional requirements of concern to the stakeholders

SCOPE

Roadway transportation

Four dimensions

ANTICIPATED WORKSHOP PRODUCTS

- **Geared to Transportation Agency Customers**
  - Transportation analysts and decision makers
  - Data collectors
  - Data managers
- **Means to Long-term Research Outcomes**
  - Adoption by transportation agencies
  - Consensus-based ingredients for standards
- **Set of Core Functional Requirements**

STAKEHOLDER GROUPS

- Group 1: Transportation Planning, Highway Construction and Asset Management
- Groups 2: Highway Safety and Incident Management
- Group 3: Traffic Management and Highway Operation
- Group 4: Transit Facilities and Operation; Commercial Vehicles and Fleet Management

DEFINITIONS

DEFINITIONS

OBJECT

Something of significance (tangible or intangible) that we want to keep information about. Objects have attributes. Attributes have values that are valid for an instant or interval time. Object's state is the object's attributes' values at an instant or interval.

EVENT

Something that happens instantaneously in a point of time that changes the state of and object (after Rumbaugh et al. 1991)

DEFINITIONS

LOCATION REFERENCING METHOD (LRM)

A mechanism for stating the location of an unknown point by referencing it to a known point (after NCHRP (1974)).

LOCATION REFERENCING SYSTEM (LRS)

Policies, records, objects, and procedures that relate the included location referencing methods (after NCHRP (1974)).

FUNCTIONAL REQUIREMENTS

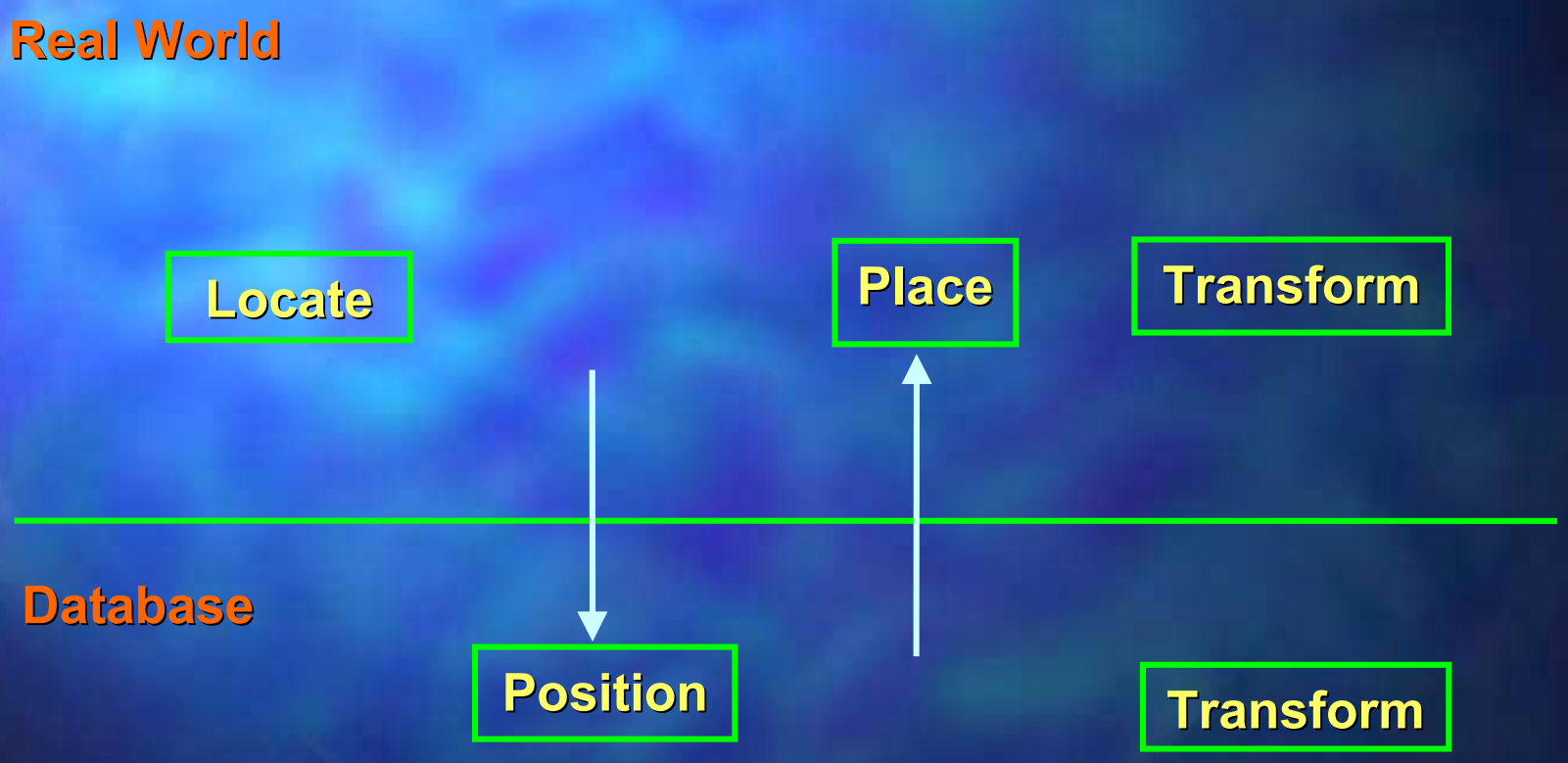
FUNCTIONAL REQUIREMENTS FOR A MULTI-MODAL MULTI-DIMENSIONAL LOCATION REFERENCING SYSTEM

1. SPATIAL / TEMPORAL REFERENCING METHODS
2. TEMPORAL REFERENCING SYSTEM / DATUM
3. TRANSFORMATION of DATA SETS
4. MULTIPLE CARTOGRAPHIC / SPATIAL TOPOLOGICAL REPRESENTATIONS
5. RESOLUTION
6. DYNAMICS
7. HISTORICAL DATABASES
8. ACCURACY and ERROR PROPAGATION
9. OBJECT-LEVEL METADATA
10. TEMPORAL TOPOLOGY / LATENCY

A comprehensive location referencing system data model…

… supports the locate, place and position processes for objects and events in three dimensions and time relative to the roadway.

DOMAIN OF BASIC OPERATORS
REAL WORLD / DATABASE



SPATIAL / TEMPORAL REFERENCES

SPATIAL

- Coordinates
- Intersections
- Street address
- Linear referencing
- Landmarks
- Custom grid references

TEMPORAL

- Half past seven
- 7:30 PM
- UTC+7h30’
- An hour ago
- Yesterday
- M-F 0900-1700
  S-Su 1000-1400 May to Oct.

Uncertainty

- Reference Object
- Offset

ALTERNATIVE SPATIAL / TEMPORAL REFERENCES

AVL/GPS	**(-111.888, 40.6993, 4,197.821)**
Address	**3330 S State SSLC**
Street Route/Milepost	**A0089 372.753**
Intersection/Offset	**3300 S & State (S) +210 ft**
Bus Route/Offset	**Rt 12 O +4.992 mi (08:50trip)**
Bus Route/ Time	**9:14 (Rt 12O 08:50 trip)**

SPATIAL / TEMPORAL REFERENCING METHODS

Specific data model requirements

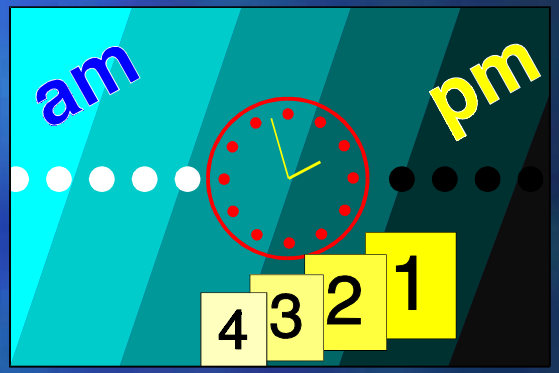
- spatial / temporal expressions specify location and time of objects and events in as many as four dimensions
- reference objects have known spatial / temporal expressions
- spatial reference objects are recoverable in the field.
- distinguishes between reference-able and non-reference-able objects

A comprehensive location referencing system data model…

... accommodates a temporal datum that relates the database representation to the real world and provides the domain for transformation among temporal referencing methods.

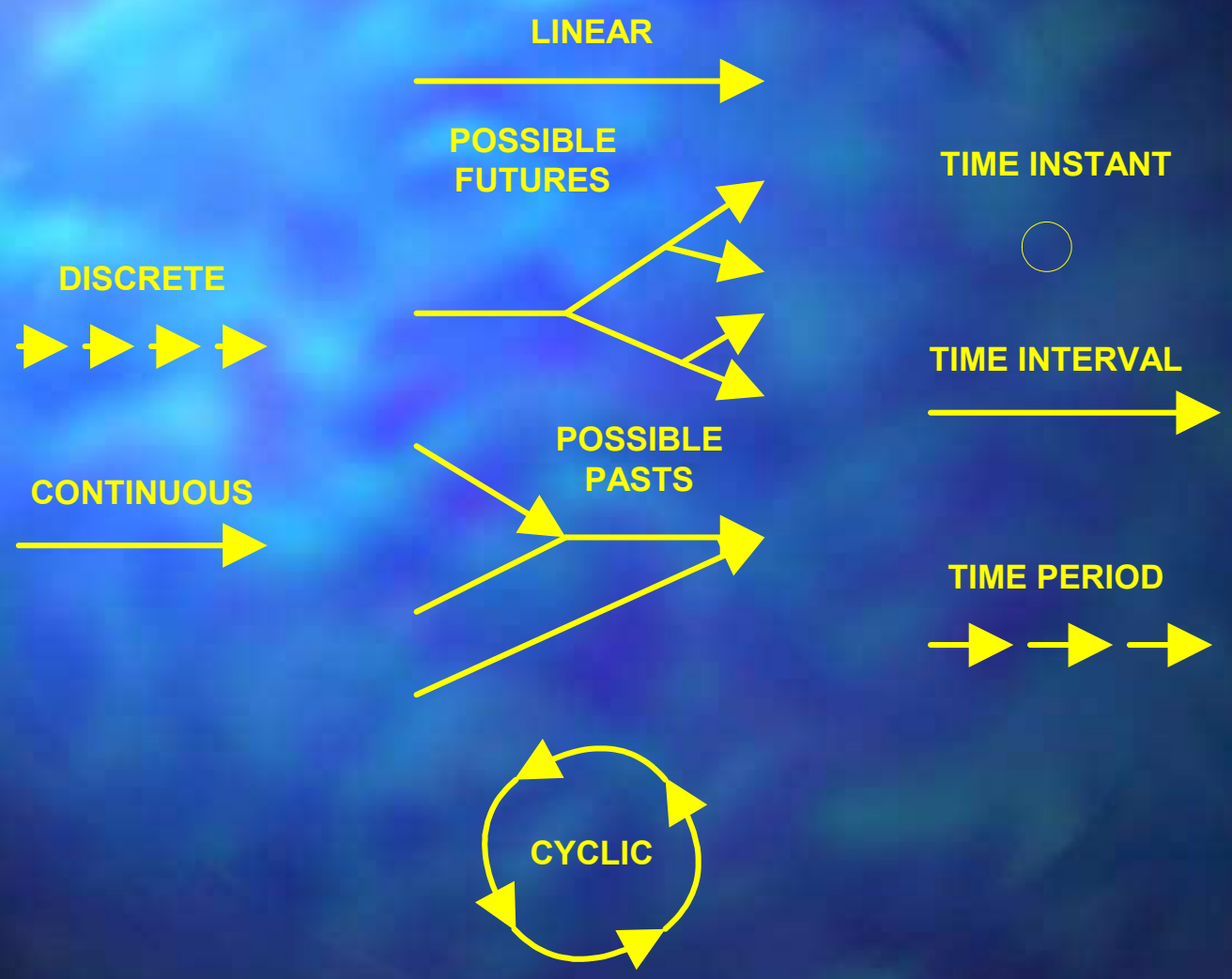
TEMPORAL REFERENCING SYSTEM / TEMPORAL DATUM

- Many Temporal Referencing Methods
  - Zone Standard Time
  - Zone Daylight Time
  - Military Time
  - Calendar Day ….



- One Temporal Referencing Datum
  - Coordinated Universal Time (Gregorian Calendar)

TIME SEMANTICS (Worboys, 1995)



TEMPORAL REFERENCING SYSTEM / TEMPORAL DATUM

Specific data model requirements

- supports multiple temporal referencing methods
- supports transformation among TRMs
- stores an explicit temporal datum (or designates on TRM as the datum) that is used as the basis for transformation among temporal referencing methods.

A comprehensive location referencing system data model…

… supports transformation between linear, non-linear, and temporal referencing methods without loss of spatial / temporal accuracy, precision, and resolution.

TRANSFORMATION

AVL/GPS — (-111.888, 40.6993, 4,197.821)

Address — 3330 S State SSLC

Street Route/Milepost — A0089 372.753

Intersection/Offset — 3300 S & State (S) +210 ft

Bus Route/Offset — Rt 12 O +4.992 mi (08:50trip)

Bus Route/ Time — 9:14 (Rt 12O 08:50 trip)

LRM to LLRM

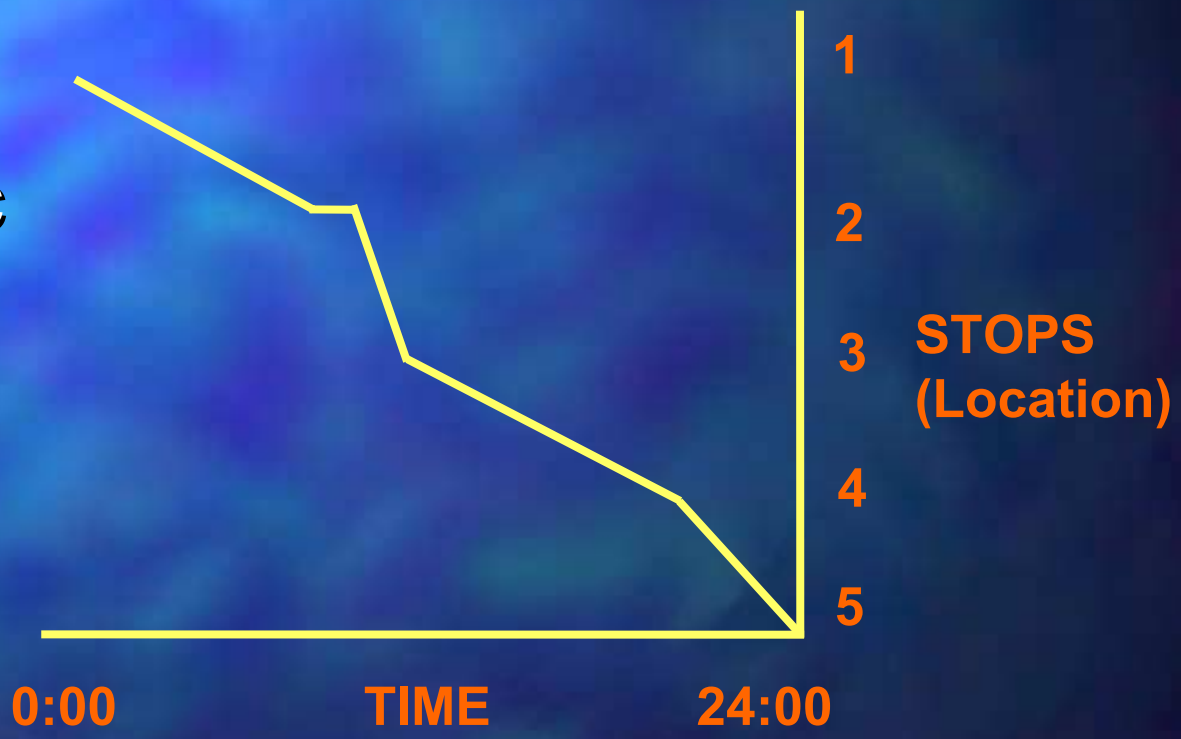
LRM to TRM

TRANSFORMATION OF DATA SETS

- Key for interoperability of data sets

TRANSFORMATION FUNCTIONS

- Something more than simple database associations
- Analytic
- Stochastic



TRANSFORMATION OF DATA SETS

Specific data model requirements

- supports transformation among spatial referencing methods (time as a constant).
  - LLRM ⇔ LLRM
  - LLRM ⇔ 2D or 3D LRM
  - 2D LRM ⇔ 3D LRM
- $LLRM_1(t_1) \Leftrightarrow LLRM_1(t_2)$
- LLRM (linear datum) ⇔ TRM (temporal datum)
- spatial / temporal referencing system provides certain accuracy and precision

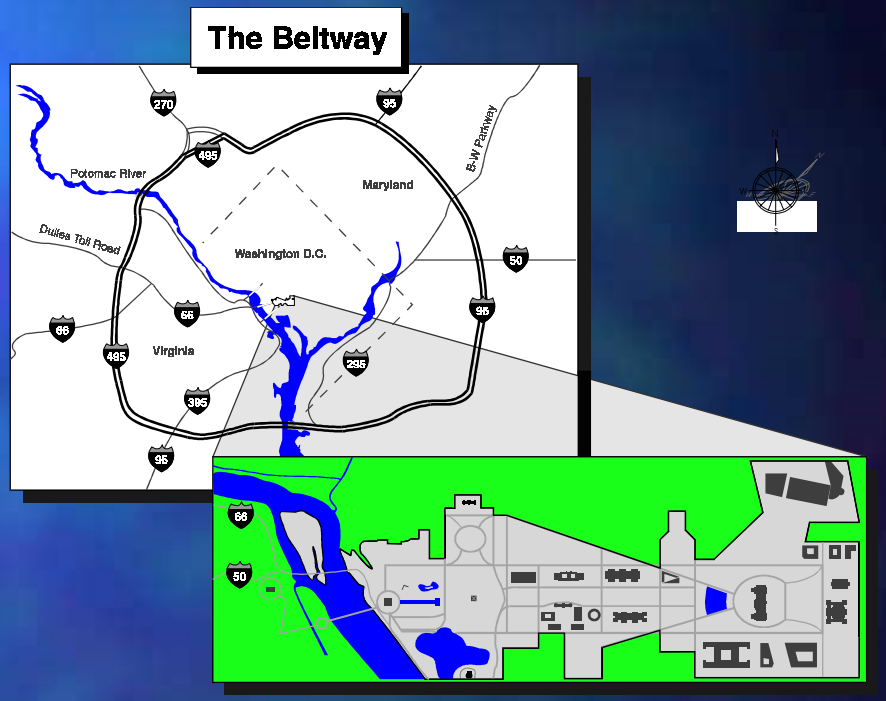
A comprehensive location referencing system data model…

… supports multiple cartographic and topological representations at both the same and varying levels of generalization of transportation objects.

MULTIPLE CARTOGRAPHIC / SPATIAL TOPOLOGICAL REPRESENTATION

- SCALE APPLICABILITY -

- Is application dependent
- Is multi-representational
- Is dependent on the interoperability of data from different sources



MULTIPLE CARTOGRAPHIC / SPATIAL TOPOLOGICAL REPRESENTATIONS

- Implied relationship between cartographic and network levels of abstraction but the relationship may not be one-to-one.
- Uncouple cartography and topology
- Application-specific
- Topology and cartography know their own aliases.
- Can be used for Generalization / Aggregation
- E.g., Represent an interchange as a node or as collection of nodes and links.

MULTIPLE CARTOGRAPHIC / SPATIAL TOPOLOGICAL REPRESENTATIONS

Specific data model requirements

- multiple spatial topological representations for individual geometric objects
- topological representation of a geometric object has one or more associated cartographic representations
- cartographic representation has one or more associated topological representations.
- changes in cartographic representation (due to change in map scale) lead to references to the appropriate topological representation
- changes in the topological representation (due to level of generalization) lead to references to the appropriate cartographic representation.
- consistent turning movements and restrictions that apply for all topological representations

A comprehensive location referencing system data model…

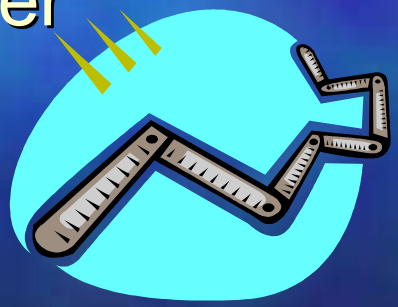
… supports the display and analysis of objects and events at multiple spatial and temporal resolutions.

RESOLUTION

Defines the granularity or detail of data obtained and analyzed.

Spatial Granularity

- kilometer
- meter
- centimeter



Temporal Granularity

- year
- month
- day
- hour
- minute

RESOLUTION

Specific data model requirements

- unrestricted resolution and dimensional representations for data collection and storage (e.g., accident can be represented as point along centerline, at lane level, as areas, and using vertical dimension)

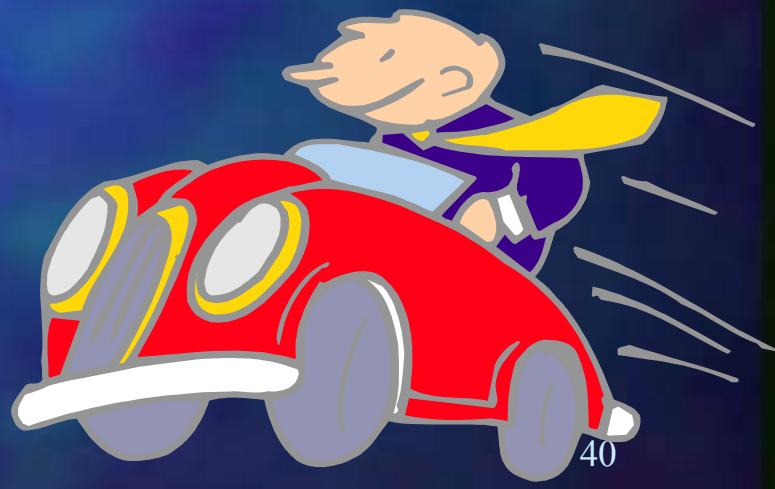
A comprehensive location referencing system data model…

… supports the navigation of objects, in near real-time and contingent upon various criteria, along a traversal in a transportation network.

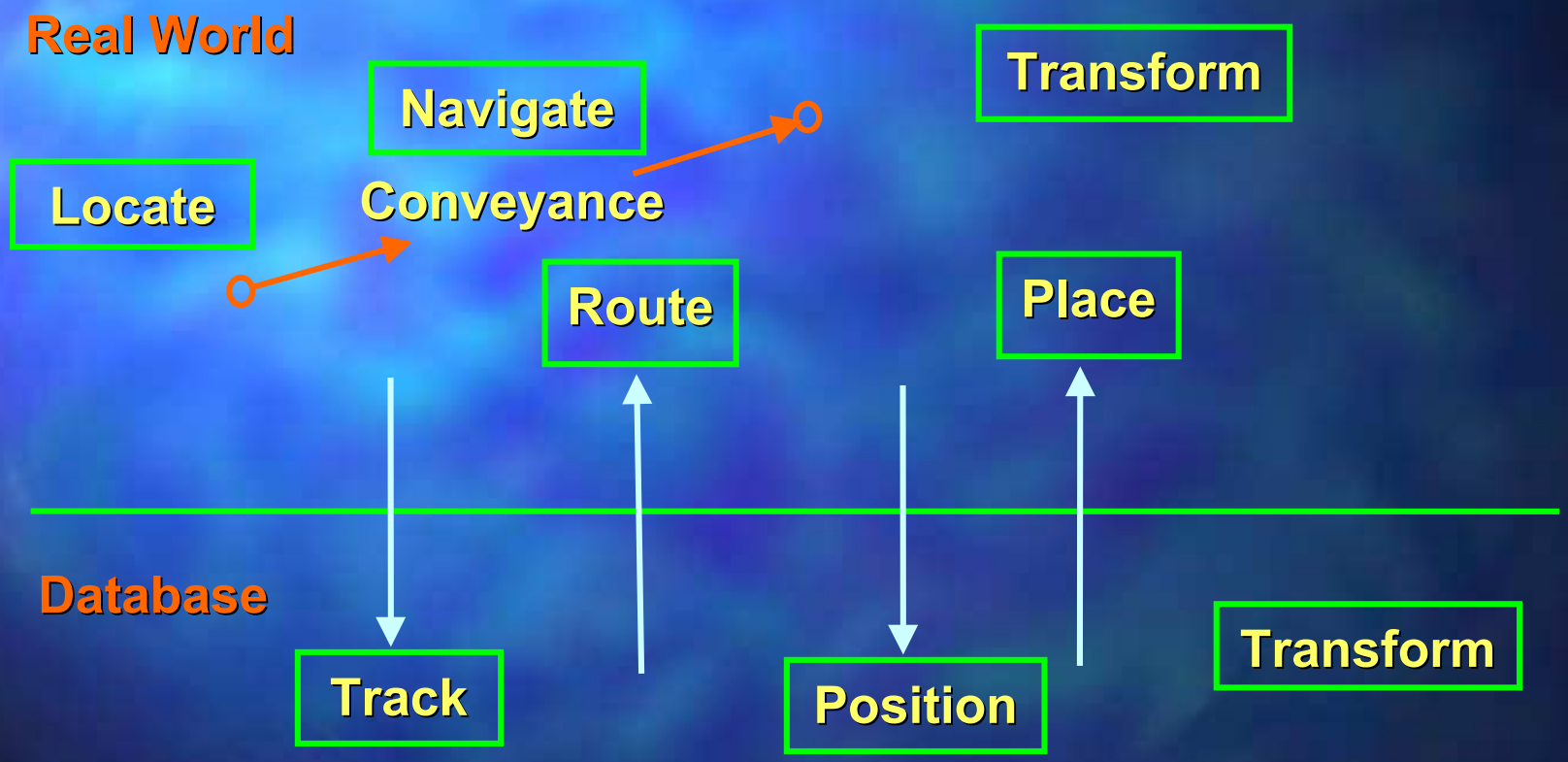
DYNAMICS

Model for Movement in Time and Space

- Addresses concepts of monitoring and guiding
- Includes free-form movement (“cruising”)
- Includes “on-the-fly” modifications to pre-planned route



DOMAIN OF BASIC / DYNAMIC OPERATORS
REAL WORLD / DATABASE



DYNAMICS

Specific data model requirements

- conveyance objects have locations that are time dependent
- temporal referencing methods provide for temporal reasoning
- for multi-modal networks, a path finding algorithm that supports proximity analysis for spatial / temporal disconnects among events and objects
- time-dependent intersection movements and restrictions
- time-dependent link attributes for temporal-based lane configurations such as HOV and reversible lanes
- events have time-dependent attributes

A comprehensive location referencing system data model…

… supports the regeneration of object and network states over time, and maintains the network event history.

HISTORICAL DATABASES

- Objects are defined by their state in time.
- Events change the state of objects.
- Historical Analysis
  - compare states of an object over time
  - compare system states
- Roll-back to link old and new objects.

HISTORICAL DATABASES

Specific data model requirement

- state histories are maintained for objects and events

A comprehensive location referencing system data model…

… supports the association of error measures with spatial / temporal data at the object-level and propagation of those errors through analytical processes.

ACCURACY AND ERROR PROPAGATION

- Objects in, and referenced to, a spatial / temporal referencing system are related by *measurements*
- All measurements contain error
- Errors in data propagate through analytical processes to produce uncertainty in results

ACCURACY AND ERROR PROPAGATION

Specific data model requirements

- measures of spatial / temporal error (bias and precision) within objects and events
- spatial / temporal auto-correlation of error among objects and events.

A comprehensive location referencing system data model…

… stores and expresses object-level metadata to guide general use.

OBJECT-LEVEL METADATA

- Metadata provides guidance for use and representation
- Metadata standard now is for entire dataset
  - Many sources of data in dataset
  - Each with an error and confidence interval
- Need metadata at the object level

OBJECT-LEVEL METADATA

Specific data model requirements

- data lineage and other metadata (such as attribute and feature quality) at the object-level

A comprehensive location referencing system data model…

… supports temporal relationships among objects and events and the latency of events.

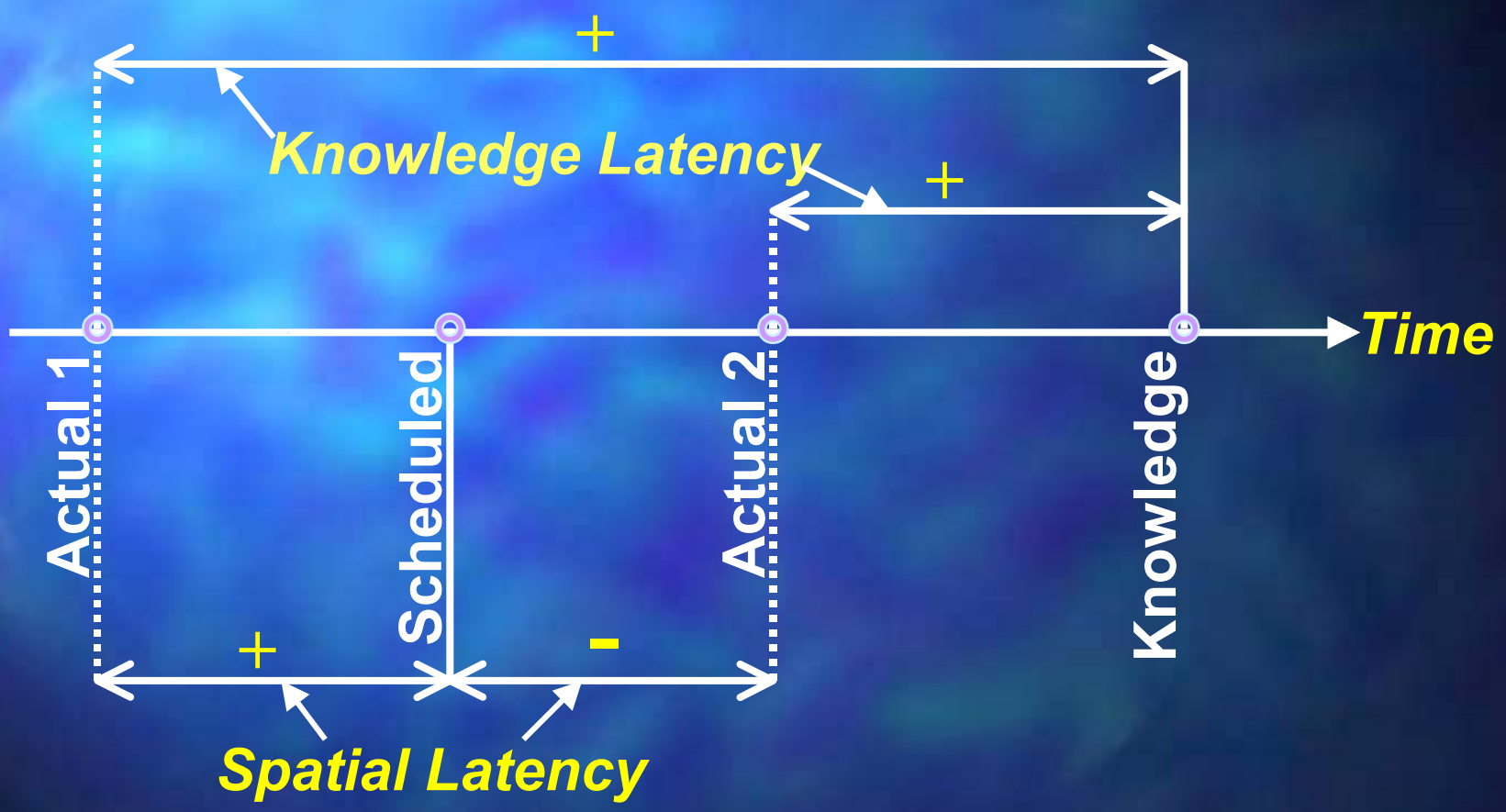
Temporal Topological Relationships (Peuquet, 1994)

RELATION	SYMBOL	X	Y
X before Y	<		
X equal Y	=		
X meets Y	m		
X overlaps Y	o		
X during Y	d		
X starts Y	s		
X ends Y	e		

TEMPORAL RELATIONSHIPS

- **Spatial / temporal proximity**
  - prevent road striping before paving.
- **Temporal within**
  - identify all projects being let in the third quarter of the year.
- **Spatial / temporal within**
  - all accidents during a construction project within a construction boundary.
- **Temporal after**
  - all accidents that occur after a project completion.

LATENCY CONCEPTS



TEMPORAL TOPOLOGY / LATENCY

Specific data model requirements

- temporal referencing method
- explicit or derivable temporal topological relationships among objects and events (disjoint, overlap, during, and simultaneous)
- recording and distinguishing between the actual and expected occurrences and durations of events
- a record of when object and event data were entered

SUMMARY & CONCLUSION

Functional Requirements are:

- Basis for a detailed data model
  - model that makes data smart
- Driven by technology
  - GIS software to visualize data
  - GPS for data collection
  - ITS applications
- Model independent