An Optimization Approach To Constraint-Based Generalization In A Commodity GIS Framework

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Introduction

• Generalization (Model and Cartographic)
  – Not many generalization tools in commodity GIS
  – Lack of contextual awareness for ones that do exist
  – AGENT project good, but tied to active object database capabilities, not in mainstream GIS

• NMAs and others want contextual generalization in commodity GIS production environment

• Research project at ESRI on an optimization approach to constraint-based generalization
  – Rule-Condition-Constraint-Action paradigm
Optimization

• Generalization as optimization
  – Optimizing both the amount of information to be presented, and the legibility/usability of the final map
  – … while conserving data accuracy, geographic characteristics, and aesthetic quality.
Concepts & History

• **Constraints**
  – Graphical, Structural, Application, Procedural

• **Optimization**
  – Statistical optimization - Metropolis 1953
  – Simulated Annealing - Kirkpatrick 1983
  – In Generalization - Ware & Jones 1998
Optimizer Prototype - Concepts

- Optimize map (set of data) against a set of rules
- Rule made up of Constraint and Action(s)
  - Constraints define the preferred state
  - Action should improve satisfaction against constraint
- Satisfaction Function for each rule
  - 0 to 1.0 means Unacceptable > Bad > Good > Excellent
- Can have Condition (predicate) for constraint
  - So can apply to subset of features
- Also have Reflex/Trigger actions
  - Good to prohibit invalid states
- Optimizer Kernel
  - Manages plan of actions, backtracks
  - ‘Simulated Annealing’ optimization technique
    - Gradually lower notional ‘temperature’
      - Avoid sticking in local minima (worse in order to get better)
Satisfaction Function

• Function is supplied by every Constraint
  – Can use all of ArcObjects to evaluate satisfaction
  – But often will be simply related to a measurable parameter, such as distance, or area

• Graph of function will vary according to constraint
  – Some will be sudden step, some smooth variation
Different levels of Satisfaction - S

Constraint satisfaction for a given feature:

\[ 0 \leq S_c(F_i) \leq 1 \]

Constraint satisfaction:

\[ S_c = \langle S_c(F_i) \rangle_i = \frac{1}{N_f} \sum_i S_c(F_i) \]

Feature satisfaction:

\[ S(F_i) = \langle S_c(F_i) \rangle_c = \frac{1}{\sum_c w_c} \times \sum_c w_c \sum_i S_c(F_i) \]

System satisfaction:

\[ S = \frac{1}{N_f} \times \sum_c w_c \times \sum_c \sum_i w_c S_c(F_i) = \langle S_c \rangle_c = \langle S(F_i) \rangle_i \]
Optimizer Prototype – Displace - Begin
Optimizer Prototype

Displace - No Barriers
Optimizer Prototype - Displace - with Barriers
Optimizer Prototype – Displacement – GP model with Barriers Prohibition
Optimizer Prototype – Satisfaction Graph
(2 constraints plus barrier prohibition)
Concept proven in DataDraw

Bus route maps - Complex graphic representation

- Rule 1: Minimize change of side and crossings (legibility)
- Rule 2: Graphic continuity
- Rule 3: End and start of routes should be on sides
- Rule 4: …
Possible Generalization Flow

Data Structure Enrichment → Partitioning → Sub-division Classification → Pattern & Group Detection

Context Analysis → Dispatch to Appropriate Algorithm → Reclassify, Aggregate Exaggerate, Simplify, Displace, Typify, ...

Loop until Done

If worse, undo

Check

Optimizer
Optimizer and GP framework

- Condition builder
- Constraint builder
- Rule builder
- Action builder
- Optimizer
- Condition
- Constraint
- Rule
- Action
Summary

• Optimization for contextual generalization
  – Looks good approach
• Rule = Constraint+Action(s)
  – Optionally [Condition+] Constraint+Action(s) [+Reflex]
• Prototype implemented as GP tools in a commodity GIS
  – Very extensible
  – Easily use GIS spatial knowledge, tools and data structures, within constraints and actions
  – Fits into automated process models for multi-scale product generation

Continuing to develop prototype and scenarios
  – And evaluating transition to product
Questions and Comments?

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This paper is a forward-looking research document, and the capabilities it describes are evolving prototypes. As such, it should not be interpreted as a commitment by ESRI to provide specific capabilities in future software releases.
Aggregation - Input Dataset

- Isolated buildings
- Narrow gaps
- Wider gaps
- Bottle necks
- Dense areas
Disadvantages of ‘classical’ Approach

- No contextual decision
- Strictness of “hard” threshold
Recast Building Centers as Triangles
What are the Constraints?

1. “little” triangles prefer to be in clusters - proximity

2. Triangles prefer being like their neighbors - coherence
   - Choose the best state for the whole triangle dataset obeying these 2 constraints.
Results of Optimization

Results generally good! Just with 2 simple constraints.

Issues with large buildings. We could triangulate building corners?
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