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A Top-down Graph-based Tool for Modeling Classical Semantic Maps: A Crosslinguistic Case Study of Supplementary Adverbs

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Background

- What is a semantic map model?
  - to visually model the similarity and entailment relations between meanings
    - (entailment: how often one meaning appears together with another in the same form?)
  - by capturing the form-meaning mappings shared across multiple languages.
  - form-meaning mappings: one-to-many relationships
    - **Content words**: polysemy, e.g., *head* can mean a *human body part* and a *leading role*
    - **Function words or affixes**: multifunctionality, e.g., *to* expresses *purpose* and *direction*
  - more straightforward and structured than descriptions written by human languages

Background

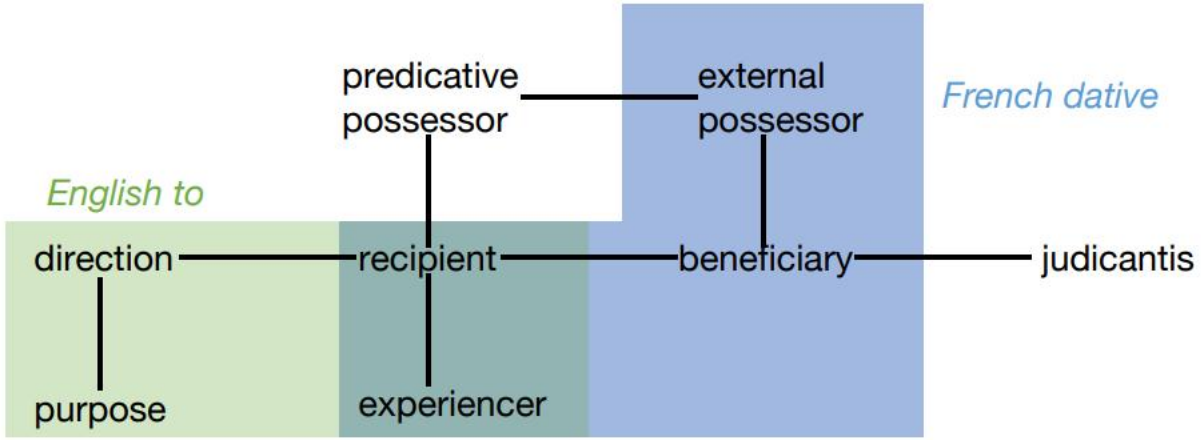
- Why study the semantic map model?
  - A widely used model in linguistic typology, dialect study, second language teaching, among others.
  - Reflect the universality of languages and limits of language variation
  - Show plausible evolutionary paths of concepts and make new predictions

Background

- How to construct a semantic map?
  - Nodes: meanings, concepts, senses or functions
  - Edges: the strenghth of association between nodes
  - Linguistic forms, e.g, content or function words, affixes, constructions
  - Form-Function Table: shows which meanings a given form can express
  - Structure Constraints: connectivity hypothesis (H1)
    - All meaning nodes associated with the same form must be connected (with the least edges).
    - (Bottom-up approach) to build a map that satisfies H1 case by case.
    - Less cyclic subgraphs: prevents overgeneralization and ensures predictive power

Example

- Domain: Dative (与事) function
- Form-function pair
  - English: Goethe went **to** Vienna as a student. (direction)
    This seems outrageous **to** me. (experiencer) ...
  - French: dative case; Spanish, Basque, etc



Haspelmath M. External possession in a European areal perspective[J]. Typological studies in language, 1999, 39: 109-136.

Motivation

- Bottom-up construction on semantic maps has several drawbacks
  - Time-consuming and difficult to scale on a larger dataset
    - Manual efforts to choose between equally plasusibe connections
    - Rollback issues, as adding new connections may require revisiting earlier ones
    - Hard to scale
  - Fail to indicate the strength of associations between two functions
    - classical vs. next-generation maps
    - classical one is more straightforward with less connections
    - Next-generation maps aim for richer representation by connecting nodes as much as possible and using numerical values to indicate the strength of associations.

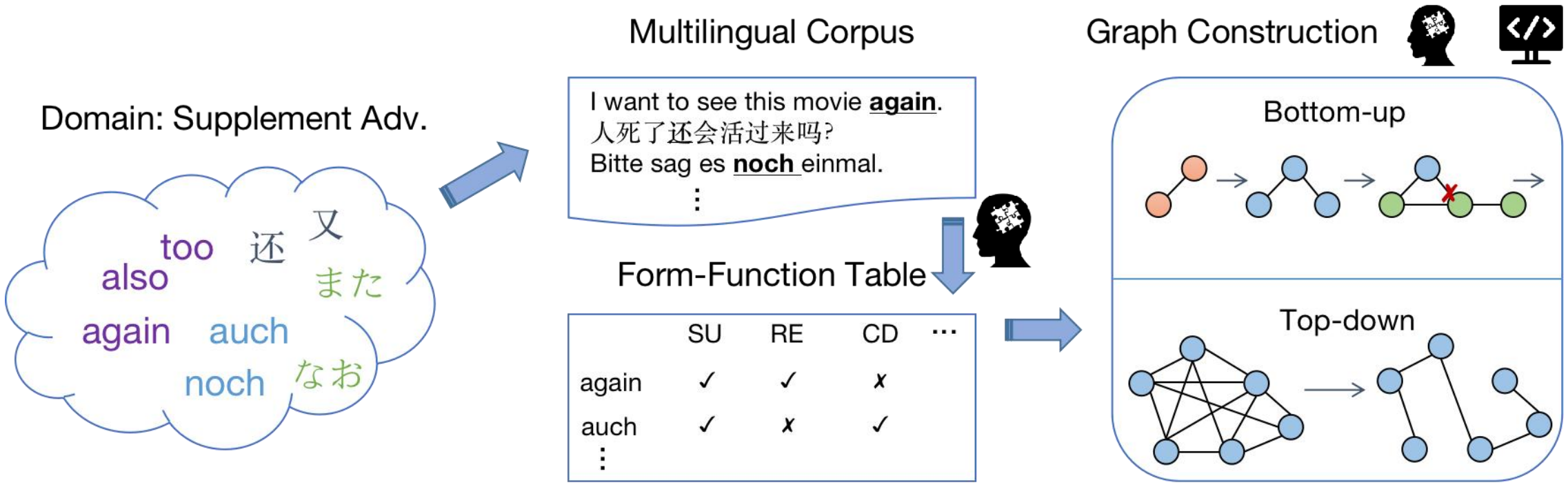
Contributions

- We propose a **top-down algorithm** to automatically generate classical semantic maps.
- We design a set of **metrics** to evaluate the quality of the resulting networks.
- A **case study on supplementary adverbs among others** demonstrates the efficiency and effectiveness of our proposed method.
- We develop a **visualization tool** based on this approach to assist typological linguists in studying multifunctionality across languages conveniently and extend it to assist SLT, evoluation, dialects, etc.

From Local to Global

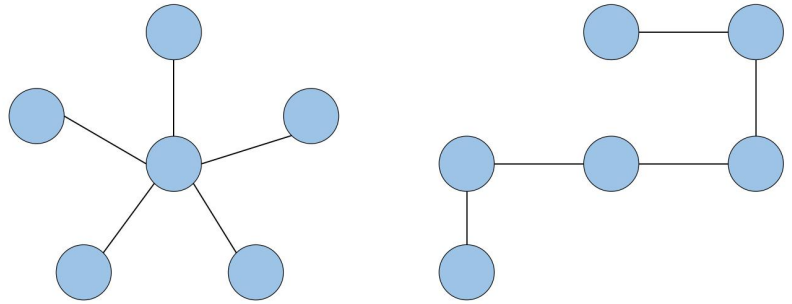
- Local connectivity hypothesis H1
  - The meaning nodes associated with a single form must be connected.
- Global hypothesis H2
  - Start with a complete graph weighted by the number of bifunctional co-occurrences.
  - The final map is a maximum spanning tree of this graph
    - Overall connectivity
    - Acylicity
    - Maximum total edge weights
  - We've prove that optimizing H2 is equal to optimizing H1.

Framework


Domain: Supplement Adv.
too
还
又
also
また
again
auch
noch
なお
Multilingual Corpus
I want to see this movie **again**.
人死了还会活过来吗?
Bitte sag es **noch** einmal.
Form-Function Table
SU RE CD ···
again ✓ ✓ ✗
auch ✓ ✗ ✓
Graph Construction
Bottom-up
Top-down

Metrics

Metric	Description	Trend
Size	Total edge weight sum	↔
Cov	Proportion of covered instances	↑
Avg_D	Average node degree	↔
Div_D	Standard deviation of node degrees	↓
Acc	Matched / total elements in $\mathcal{G}$	↑
Prec	Matched edges / generated edges	↑
Rec	Matched edges / annotated edges	↑
F1	Harmonic mean of Prec and Rec	↑



(a) std = 1.6

(b) std = 0.5

Zhu Liu, Zhen Hu, Lei Dai, and Ying Liu. “XISM: An Exploratory and Interactive Graph Tool to Visualize and Evaluate Semantic Map Models.” arXiv:2507.04070, 2026.

Evaluation

- A case study on: Supplementary Adverbs
  - e.g., 她买了菜，还做了饭 (补充); 我明天还来 (重复); If you fail, you have to take it again. (重复) After then years in prison, he was a free man again. (还原)
  - 36 languages/dialects, 82 grammatical forms and 18 functions
  - The form-function table has been created by linguists
  - The golden map (GT) serves as a reference standard

- Baselines
  - C: a complete graph
  - LT: a lower-bound one with a random **tree** that does not overlap with GT
  - LLM: Qwen3-Max by a knowledge-driven prompt

Instruction for LLM

- Imagine you are a typological linguist. Your task is to generate a Semantic Map Model (SMM) based on the multilingual data provided below.
- Objective: The first generation of SMMs should produce a graph of semantic associations, where: Nodes represent semantic functions. Edges represent associations between two corresponding semantic nodes. The graph is constructed from a form-function table, where: 1 indicates that a form (e.g., a word in a particular language) expresses a given function. 0 indicates that it does not.
- Graph Constraints: (1) Connectivity constraint: For each form, the set of semantic functions it expresses must induce a connected subgraph in the overall semantic map. (2) Minimality constraint: Use as few edges as possible, avoiding cycles whenever possible.
- Input Data Format: ...
- Output Data Format: ...

Form-function table

L	G	AF	SU	RE	CO	GD	DE	IS	CD	DC	PT	SC	WH	SE	SC	IC	UE	BL	DS
ZH	还	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0
	又	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1
	也	1	1	0	0	0	0	0	1	1	1	1	0	0	1	0	0	1	0
	在	0	1	1	1	1	0	1	0	0	0	0	1	1	0	0	0	0	0
BO	ra	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0
	tarong	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1
EN	also	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	too	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	again	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	still	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0
DE	auch	1	1	0	0	0	0	0	1	0	1	1	0	0	1	0	0	0	0
	noch	0	1	1	1	1	1	0	1	1	0	0	1	0	0	0	1	1	0
FR	aussi	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	encore	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
RU	tbzhe	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
	opyat	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JA	も	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
	また	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	なお	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
KO	도	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
	더	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	또	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	다시	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	아직	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VI	cũng	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	0
	nữa	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	còn	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0
	lại	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0

Abbr	Full
AF	Additive Focus
SU	Supplement
RE	Repetition
CO	Continuation
GD	Greater Degree
DE	Decrement
CD	Condition
DC	Discretional Condition
PT	Polarity Trigger
SC	Serious Condition
WH	Whatever
SE	Sequence
SD	Sequential Coordinator
IC	Inconsistency
UE	Unexpectedness
BL	Bottom Line
DS	Discourse Continuation

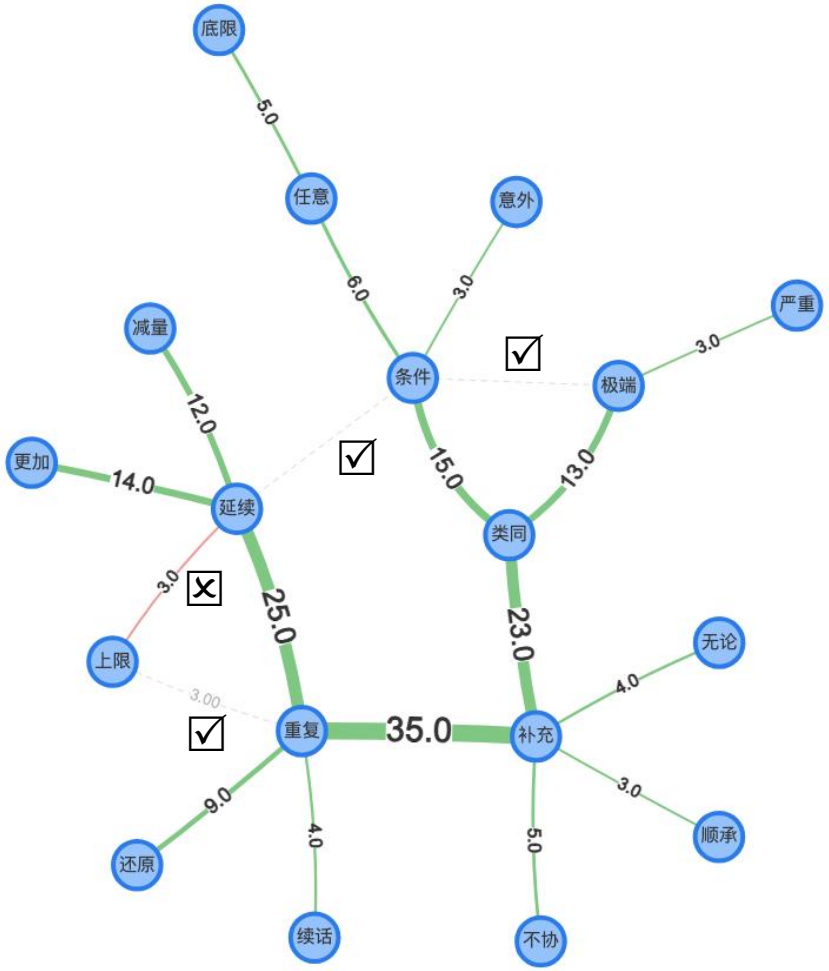
Results

G - Complete graph
LT - Random Trees
GT - Ground Truth
LLM - LLM Prompt

ours
Merged - merged after ours

	Size	Cov↑	Avg_D	Div_D	Acc↑	Prec↑	Rec↑	F1↑
G	453	100	12.111	3.542	44.44	17.4	100	29.69
LT	72	12.6	1.889	0.970	82.7	23.5	21.1	22.2
GT	201	100	2.111	1.560	100	100	100	100
LLM	151	74.4	1.889	3.213	82.7	23.5	21.1	22.2
1 (ours)	182	92.7	1.889	1.242	96.3	88.2	78.9	83.3
2 (ours)	182	92.7	1.889	1.286	**97.5**	**94.1**	**84.2**	**88.9**
3 (ours)	182	91.5	1.889	1.449	95.1	82.4	73.7	77.8
4 (ours)	182	91.5	1.889	1.663	93.8	76.5	68.4	72.2
5 (ours)	182	91.5	1.889	1.696	95.1	82.4	73.7	77.8
Merged	201	100	2.111	1.560	98.8	94.7	94.7	94.7

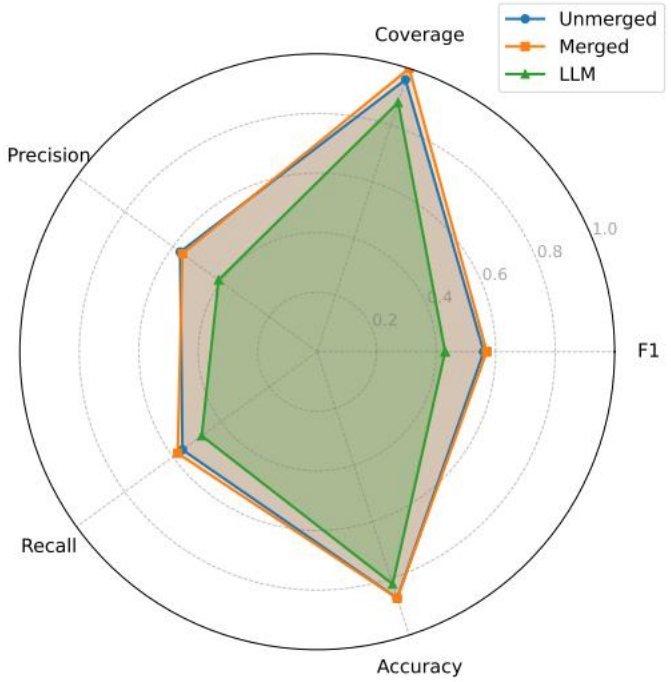
Evaluation



- We can generate comparable semantic maps to experts
- The failure cases mainly caused by the acyclic constraints
- Our edges effectively represent the degree of association between nodes.

Other cases

Name	Source	#L	#F	#Fc	Sparsity	Avg_D	Div_D	#Edges
Supplementary Adv.	(Guo, 2010)	36	82	18	0.816	2.111	1.560	19
EAT verbs	(Deng, 2020)	42	42	17	0.648	1.882	1.711	16
Ditransitive	(Guo, 2013)	6	29	34	0.737	1.941	1.454	33
And *He*	(Zhai, 2015)	55	55	29	0.801	2.000	1.509	29
What *Shenme*	(Noda, 2015)	25	44	20	0.556	2.900	2.142	29
Quantifier	(Li, 2011)	90	90	14	0.590	1.857	1.059	13
Make *Zuo*	(Liu, 2024)	17	17	8	0.375	1.750	1.090	7
Hit *Da*	(Liu, 2024)	14	14	19	0.417	1.895	2.292	18
Come *Lai*	(Liu, 2024)	14	14	8	0.420	1.750	1.392	7
Tree/Wood/Forest	(Georgakopoulos and Polis, 2018)	4	13	5	0.692	1.600	0.800	4

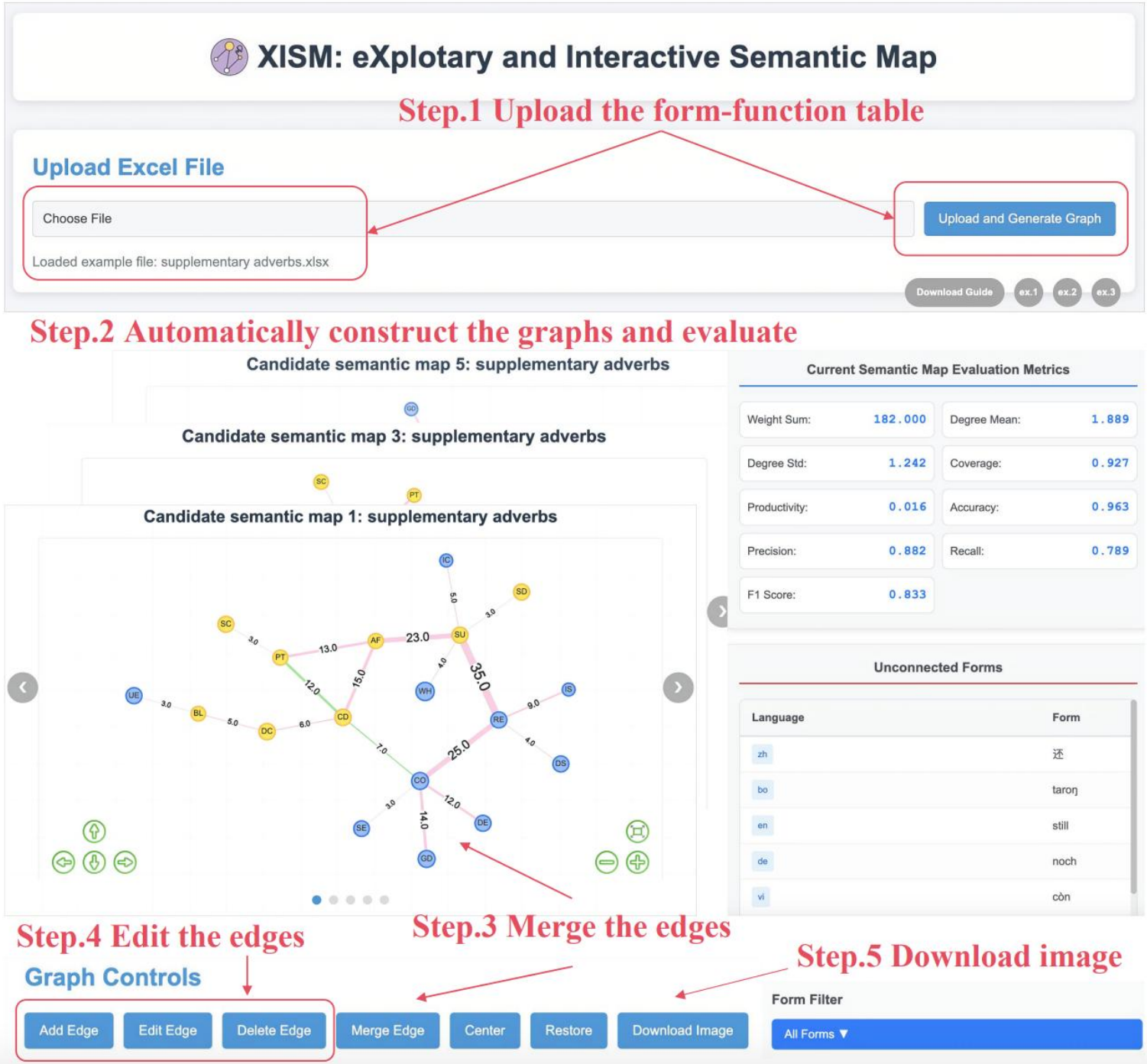


Please refer to our paper for more details.

Interactive Tool

https://www.youtube.com/watch?v=m5laLhGn6Ys

https://app.xism2025.xin/



Take away

- A **top-down approach** to build classical semantic model maps
- **Metrics** to evaluate the map automatically
- A **visualization tool** for linguists

References

- (Martin Haspelmath. 2003.) The geometry of grammatical meaning: Semantic maps and cross-linguistic comparison. In Michael Tomasello, editor, The new psychology of language, volume 2, pages 211–243. Lawrence Erlbaum, Mahwah, NJ.
- Zhu Liu, Cunliang Kong, Ying Liu, and Maosong Sun. “A Top-down Graph-based Tool for Modeling Classical Semantic Maps: A Crosslinguistic Case Study of Supplementary Adverbs.” NAACL 2025, Albuquerque, New Mexico.
- Zhu Liu, Zhen Hu, Lei Dai, and Ying Liu. “XISM: An Exploratory and Interactive Graph Tool to Visualize and Evaluate Semantic Map Models.” arXiv:2507.04070, 2026.

Thank you for your attention!

Paper v1

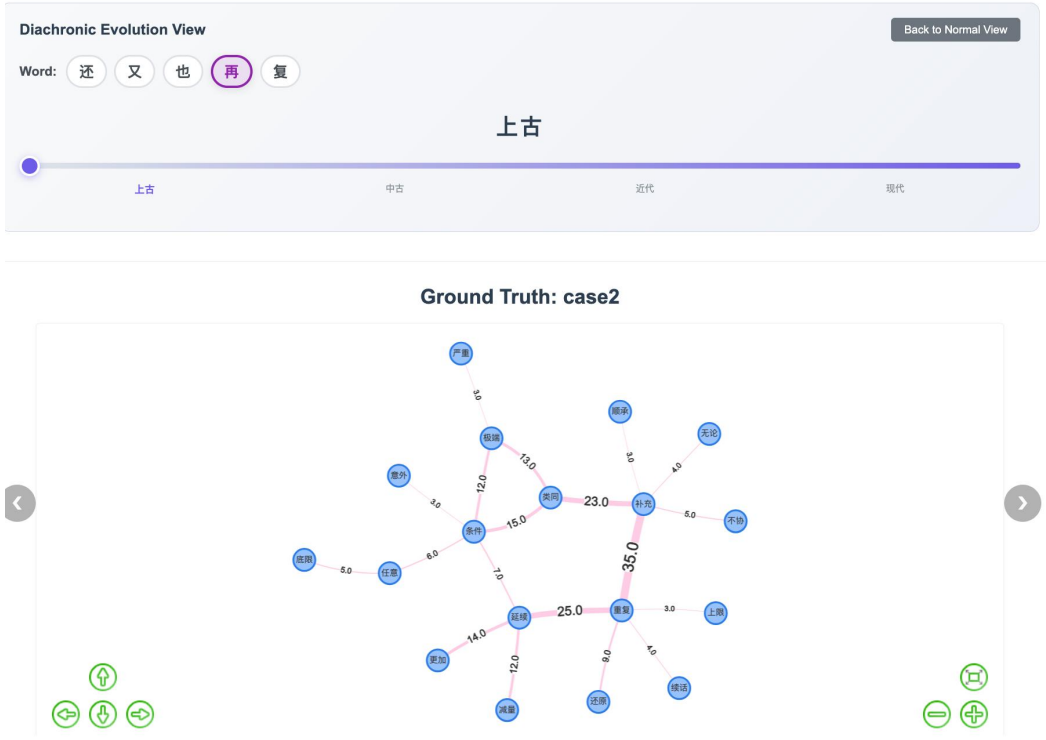
Paper v2

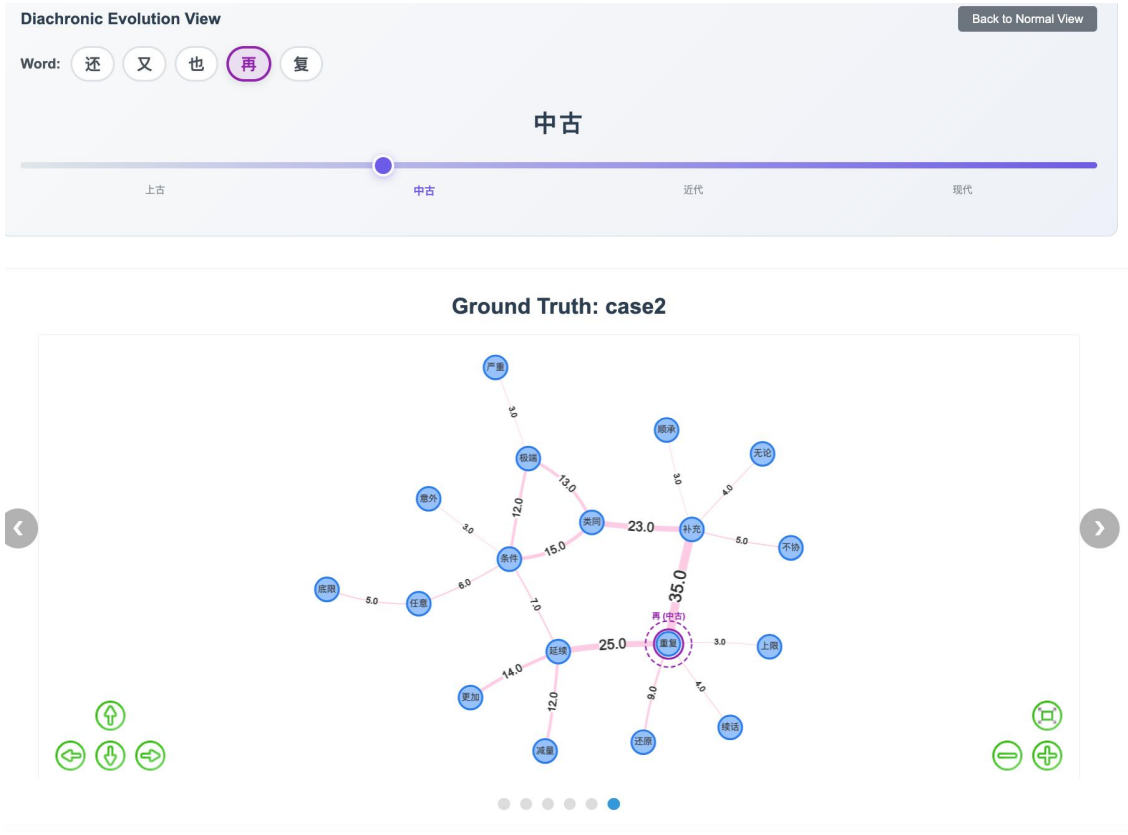
Code

Personal Website

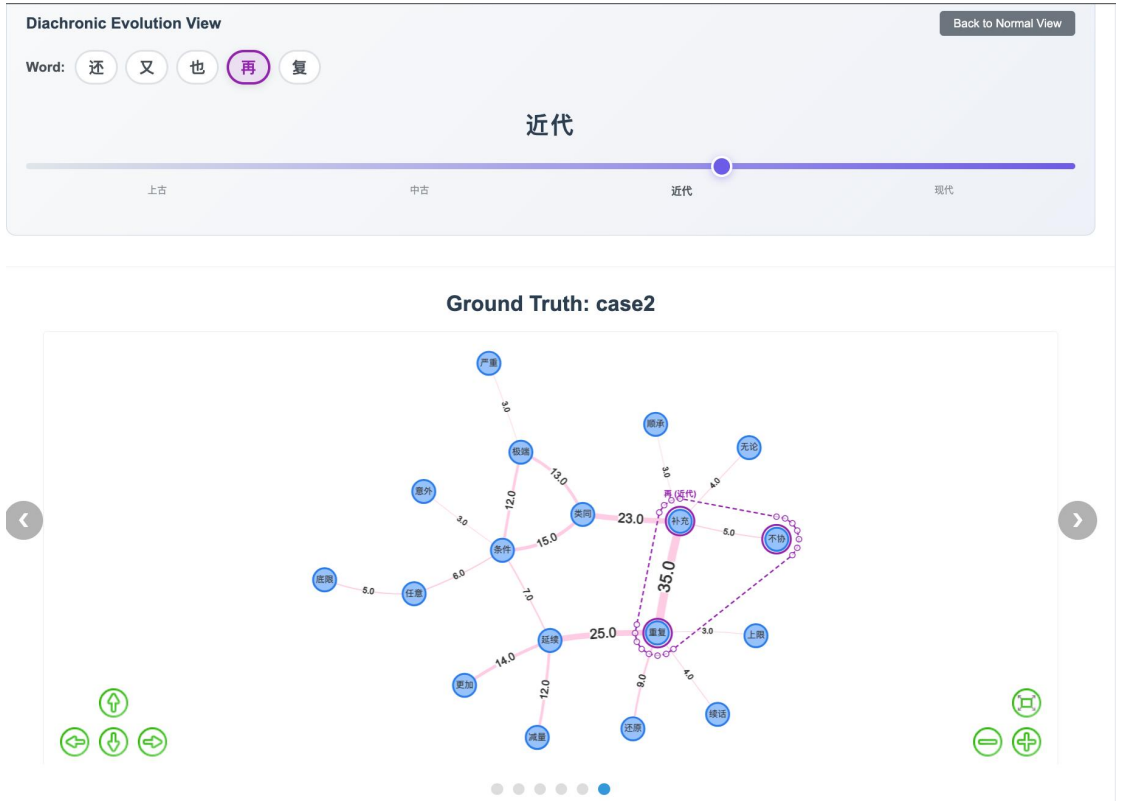
Welcome to our poster session: from 12:30 to 13:40 on 30th August!

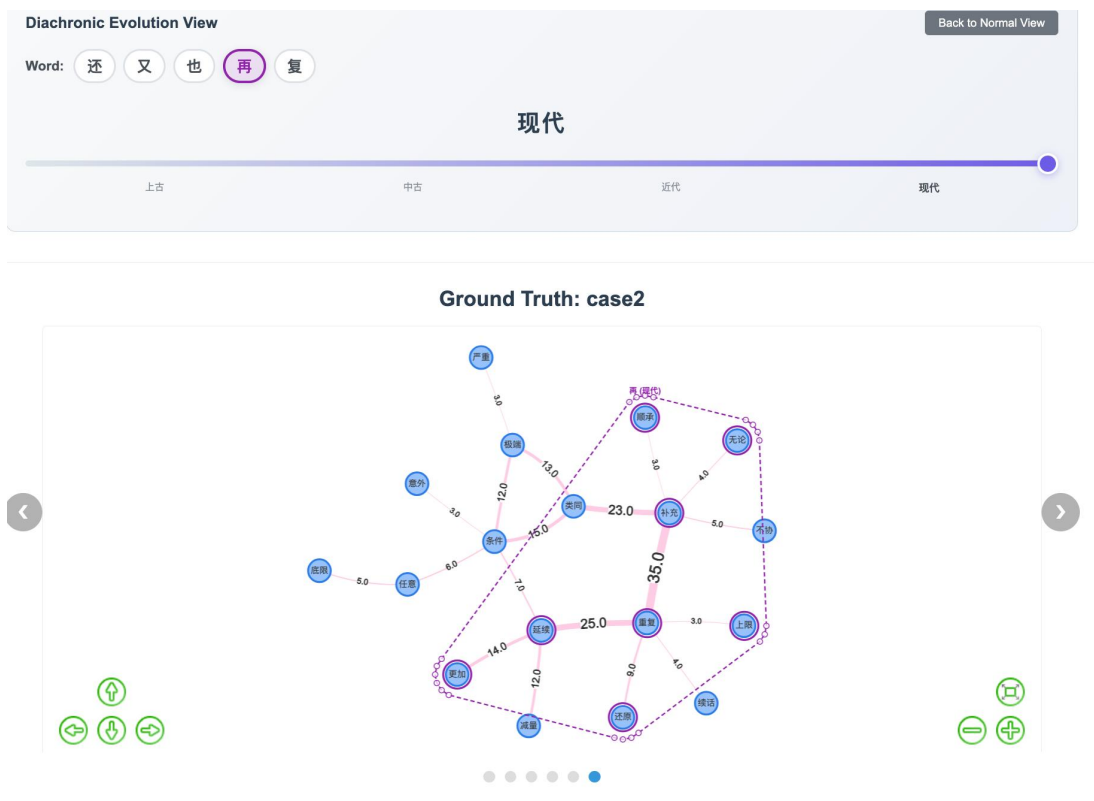
SMM for Evolution





SMM for Evolution





SMM for SLA


初级 (2)
中级 (3)
高级 (6)
Second Language Acquisition View
Back to Normal View
Native Language:
韩语
Target Language:
汉语
Form:
做
Proficiency:
初级
Concept Space for: 做 | Native: 韩语 | Target: 汉语 | Level: 初级 | Active features: 2 | Forms: 17 | Matched forms: 0
语义地图 6: SLA: 做 (初级)
举行
14.494
假装
从事
15.4
3.624
制造
11.776
7.247
担任
结成
4.529
4.538
写作
当作

SMM for Dialect Study