PanLex: Using PostgreSQL to implement a massive word-translation graph

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THE LONG NOW FOUNDATION

PanLex overview

- Non-profit project of The Long Now Foundation
- Mission: overcome language barriers to human rights, information, and opportunities
  - focus on small, under-served language communities
- Main product: database connecting every word in every language
  - 2,500 dictionaries
  - 5,700 languages (of about 7,000 in the world)
  - 25 million expressions (~words)
  - 1.3 billion direct pairwise translations
  - freely available

Presentation topics

- Database goals
- Database schema
- Word-translation query examples
  - direct (attested) translations
  - indirect (inferred) translations
  - translation quality algorithms
- Strategies we’ve used to optimize performance

Database design goals

- Given a word in *any* language, get back translations in *any* other language
- Don't make data model so rich or restrictive that it can't support the limited data available for many smaller languages
  - require only words in usual written form
  - optional: part of speech, semantics, irregular forms, pronunciation, etc.
  - make it possible to ingest widely available data (e.g. Wiktionary)
- Make it possible to infer new translations not directly attested in any source

Database coverage: top 20 language varieties

language	num. expressions	language	num. expressions
English	2,966,334	Uyghur (Arabic script)	396,771
Mandarin (Simplified)	1,661,698	Uyghur (Latin script)	350,252
Russian	1,203,275	Czech	338,493
French	691,415	Finnish	332,508
German	686,887	Portuguese	298,375
Mandarin (Pinyin)	637,854	Polish	287,792
Japanese	592,244	Dutch	284,054
Spanish	561,276	Arabic	278,293
Italian	488,153	Esperanto	265,415
Mandarin (Traditional)	469,780	Hindi	264,541

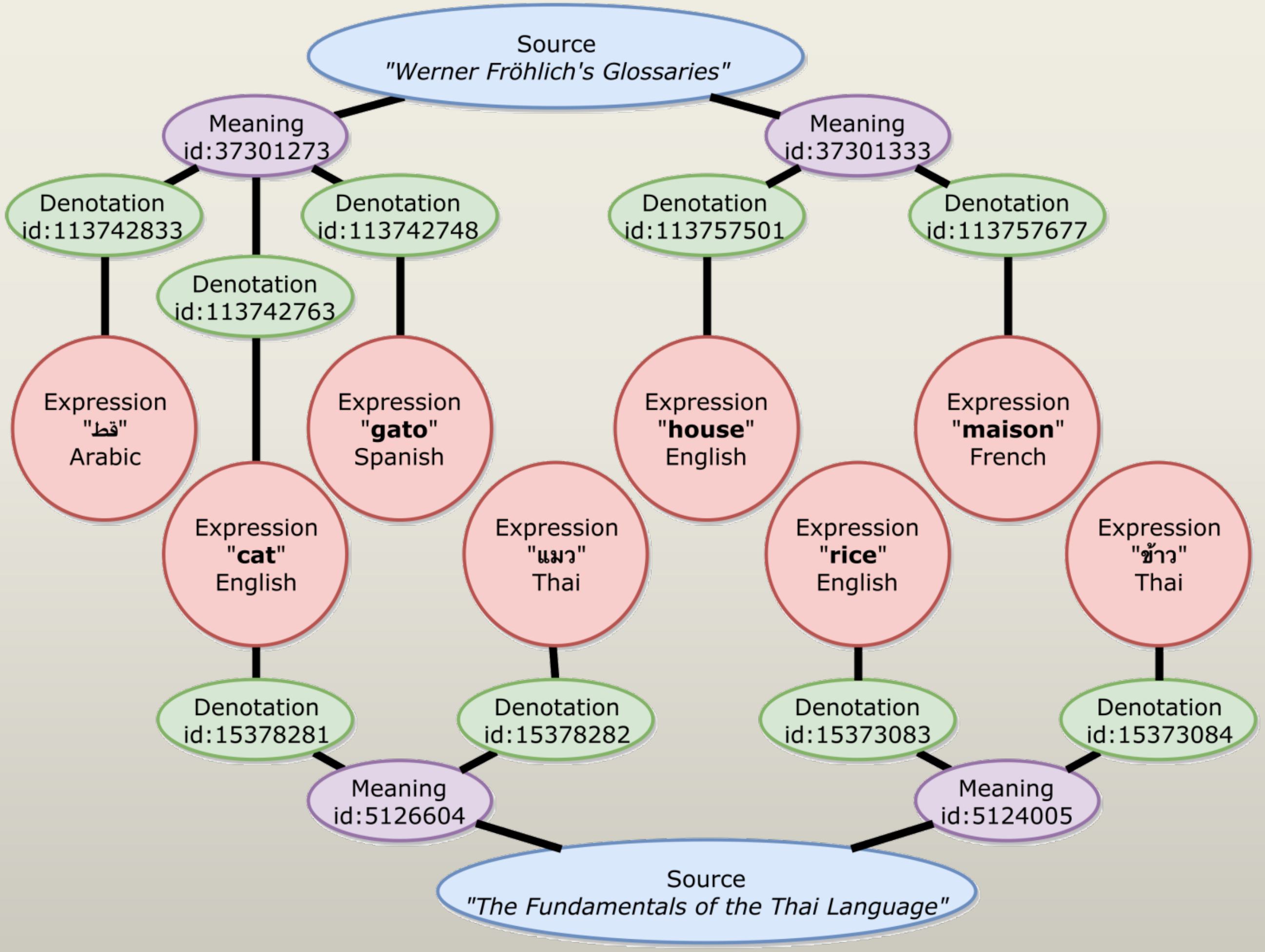
PanLex database concepts 1

- *language*: the set of linguistic varieties designated by a single ISO 639 three-letter code (`eng` = English, `cmn` = Mandarin, etc.)
- *language variety*: particular variety of a language (distinguished by dialect, script, etc.)
- *expression*: string of characters in a language variety, representing a word or word-like phrase (“try”, “try out”, “trial and error”)
- *resource*: anything that documents equivalences among expressions (dictionary, thesaurus, thematic word list, database, etc.)
- *source*: logical chunk of a resource, as represented in PanLex (if not whole resource, could be each direction of a bilingual dictionary)

PanLex database concepts 2

- *meaning*: single set of inter-translated expressions from a source (always belongs to **one** source!)
- *denotation*: pairing of an expression with a meaning in a source
- *translation*: two expressions that are (arguably) equivalent
  - direct: explicitly attested in some PanLex source
  - indirect: inferred by combining multiple PanLex sources
- translation examples
  - English "couch" = English "sofa"
  - English "cat" = Spanish "gato" = German "Katze" (3 pairwise translations)

Database schema illustration



Source table definition

```
CREATE TABLE source (
    id serial PRIMARY KEY,
    label text NOT NULL UNIQUE,
        -- standardized human-readable label e.g. ‘eng-spa-Smith’
    quality smallint NOT NULL,
        -- ranges from 0 to 9
    grp integer NOT NULL REFERENCES source(id)
        -- groups sources together from the same resource
);
```

Expression table definition

```
CREATE TABLE expr (
    id serial PRIMARY KEY,
    langvar integer NOT NULL REFERENCES langvar(id),
    txt text NOT NULL,
    UNIQUE (txt, langvar)
);
```

Meaning and denotation table definitions

```
CREATE TABLE meaning ( -- translation set from a source
    id serial PRIMARY KEY,
    source integer NOT NULL REFERENCES source(id)
);

CREATE TABLE denotation ( -- links expression and meaning
    id serial PRIMARY KEY,
    meaning integer NOT NULL REFERENCES meaning(id),
    expr integer NOT NULL REFERENCES expr(id),
    UNIQUE (meaning, expr)
);
```

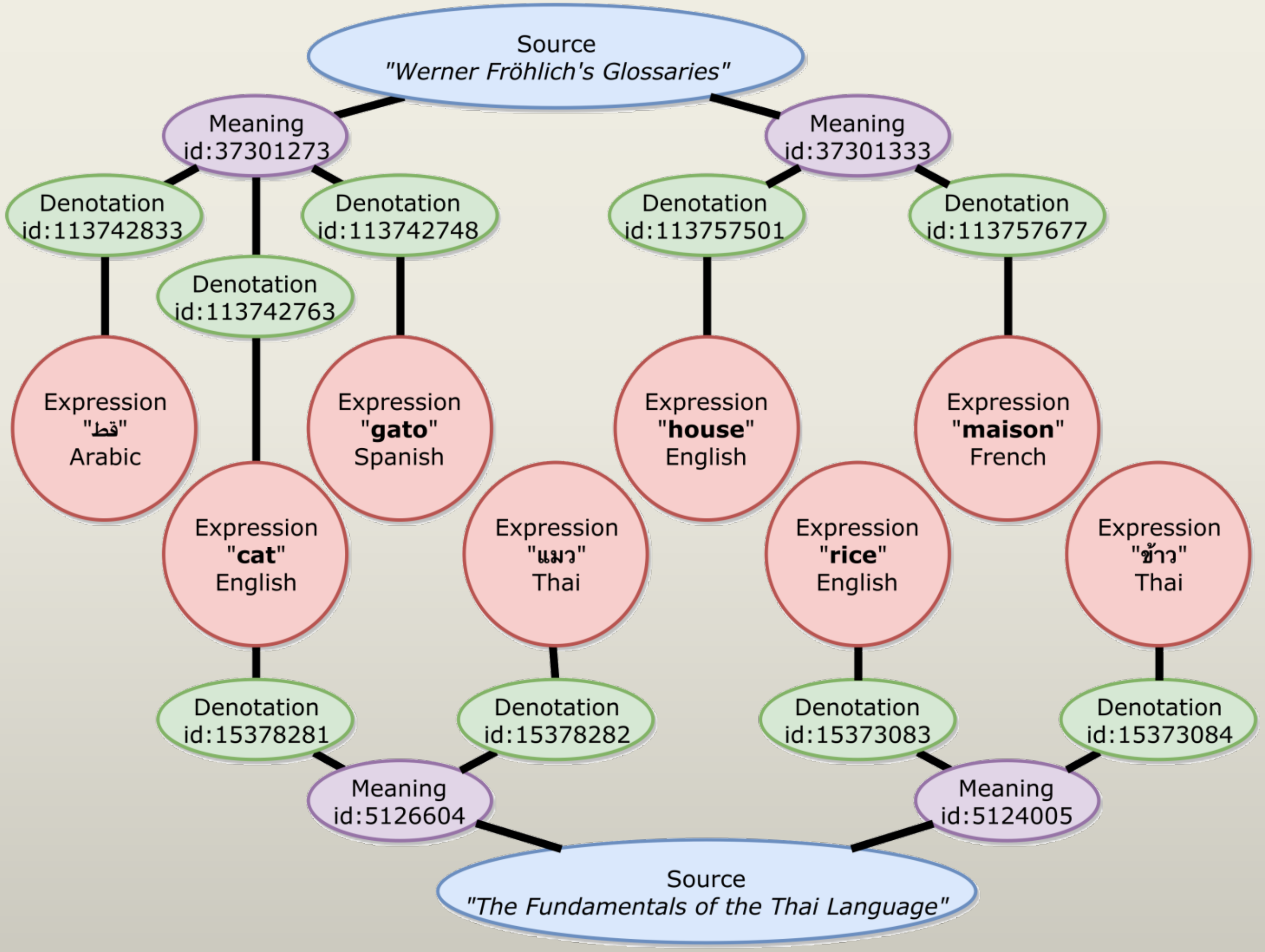
Denotationx table definition (denormalized)

```
CREATE TABLE denotationx ( -- denormalized denotation
    id integer NOT NULL REFERENCES denotation(id),
    meaning integer NOT NULL, -- denotation.meaning
    expr integer NOT NULL, -- denotation.expr
    langvar smallint NOT NULL, -- denotation.expr.langvar
    source smallint NOT NULL, -- denotation.meaning.source
    grp smallint NOT NULL, -- denotation.meaning.source.grp
    quality smallint NOT NULL, -- denotation.meaning.source.quality
    UNIQUE (meaning, expr)
);
```

Schema design decisions

- Meaning-denotation-expression design creates some level of indirection, but allows translation sets to be arbitrarily large
  - translation set with 500 expressions has 124,750 undirected pairs
  - gets costly to derive and store each pair
- PanLex concept of meaning is aspirational, not literal (confusingly)
  - two sources documenting an equivalence between English "cat" and Spanish "gato" will create *two different* PanLex meanings, despite having the same linguistic meaning
  - because can't always be sure which PanLex meanings have the same linguistic meaning: which did dictionary author intend? think of words like "bank" (financial institution vs. edge of river), "play" (verb vs. noun meaning theater piece)
  - aspiration to eventually merge PanLex meanings that share the same linguistic meaning (not easy!)

How would you write a translation query?



Direct translation query

English “eggplant” → Spanish

```
SELECT DISTINCT expr.id, expr.txt
FROM expr
JOIN denotationx AS d ON d.expr = expr.id
JOIN denotationx AS d_src ON d_src.meaning = d.meaning AND
  d_src.expr != d.expr
WHERE expr.langvar = 666 AND d_src.expr IN (SELECT expr.id FROM
  expr WHERE expr.langvar = 187 AND expr.txt = 'eggplant');
```

- NB: `langvar` 666 = Spanish, 187 = English

Direct translation query

English “eggplant” → Spanish

id	txt
654994	berenjena
8368676	aubergine
8374926	manzana de amor
20909249	solanum melongena
23225336	color berenjena

- Results are good, but unordered and don’t know which is “better”

Direct translation query with quality

English “eggplant” → Spanish

```
SELECT expr.id, expr.txt, grp_quality_score(array_agg(d.grp),
  array_agg(d.quality)) AS trans_quality
FROM expr
JOIN denotationx AS d ON d.expr = expr.id
JOIN denotationx AS d_src ON d_src.meaning = d.meaning AND
  d_src.expr != d.expr
WHERE expr.langvar = 666 AND d_src.expr IN (SELECT expr.id FROM
  expr WHERE expr.langvar = 187 AND expr.txt = 'eggplant')
GROUP BY expr.id
ORDER BY trans_quality DESC;
```

Implementation of grp_quality_score

```
CREATE FUNCTION grp_quality_score(grp integer[], quality
  smallint[]) RETURNS integer LANGUAGE sql IMMUTABLE AS $$
SELECT sum(max_quality)::integer
FROM (
  SELECT max(quality) AS max_quality FROM (
      SELECT * FROM unnest(grp, quality) AS u(grp, quality)
    ) a
    GROUP BY grp
  ) b
$$;
```

Direct translation query with quality: result

English “eggplant” → Spanish

id	txt	trans_quality
654994	berenjena	65
23225336	color berenjena	7
20909249	solanum melongena	3
8368676	aubergine	2
8374926	manzana de amor	2

What about a less typical pair of languages?

- Probably don't have an Irish Gaelic–Moor dictionary…

Indirect translation query

Irish Gaelic “madra” (dog) → Moor

```
SELECT expr.id, expr.txt, grp_quality_expr_score_geo2(array_agg(d.grp),
  array_agg(d_src.grp), array_agg(d.quality), array_agg(d_src.quality),
  array_agg(d2.expr)) AS trans_quality
FROM expr
JOIN denotationx AS d ON d.expr = expr.id
JOIN denotationx AS d2 ON d2.meaning = d.meaning AND d2.expr != d.expr
JOIN denotationx AS d3 ON d3.expr = d2.expr
JOIN denotationx AS d_src ON d_src.meaning = d3.meaning AND d_src.grp
  != d.grp AND d_src.expr != d.expr AND d_src.expr != d3.expr
WHERE expr.langvar = 886 AND d_src.expr IN (SELECT expr.id FROM expr
  WHERE expr.langvar = 238 AND expr.txt = 'madra')
GROUP BY expr.id
ORDER BY trans_quality DESC;
```

Implementation of grp_quality_expr_score_geo2

```
CREATE FUNCTION grp_quality_expr_score_geo2(grp1 integer[], grp2
  integer[], quality1 smallint[], quality2 smallint[], expr2 integer[])
  RETURNS integer LANGUAGE sql IMMUTABLE AS $$
SELECT round(sum(sqrt(b.quality1*b.quality2)))::integer
FROM (
  SELECT max(a.quality1) AS quality1, max(a.quality2) AS quality2
  FROM (
    SELECT * FROM unnest(grp1, grp2, quality1, quality2, expr2) AS
      u(grp1, grp2, quality1, quality2, expr2)
  ) a
  GROUP BY a.grp1, a.grp2, a.expr2
) b
$$;
```

Indirect translation query: result

Irish Gaelic “madra” (dog) → Moor

id	txt	trans_quality
7409488	auna	2692
7409578	savaʔu	6
18744101	ma7a	5

Indirect translation: top intermediate languages

Irish Gaelic "madra" (dog) → Moor

langvar	times used	langvar	times used
English	44	hrvatski	15
Esperanto	34	Malti	14
Tagalog	19	hornjoserbšćina	12
bokmål	17	Iloko	12
català	17	føroyskt	12
eesti	17	bosanski	11
latviešu	17	Volapük	10
brezhoneg	16	basa Jawa	9
bahasa Indonesia	16	Bahasa Malaysia	9
slovenčina	15	isiZulu	9

Performance observations

- Denormalized `denotationx` table is a big win overall
  - reduces number of joins (especially in indirect translation queries)
  - uses less memory
  - produces better query plans
- Translation queries benefit from having working set (`expr` and `denotationx` tables and indexes) loaded into memory
  - single dedicated server with 128GB of RAM hosts PanLex database
  - extra memory at lower price point (no cloud) is worth the loss of flexibility/scalability
  - (keep in mind: PanLex is a small project with limited staff)

By the way, you can do more than just translation with PanLex…

- Generate fake words in a language using a Markov-chain model
- English examples:
  - hired mullet
  - adjustache
  - nuclear souffle
  - predestructural struction
  - garbling port
  - telephantability
  - pepperonism
  - vermicrosoft driverian