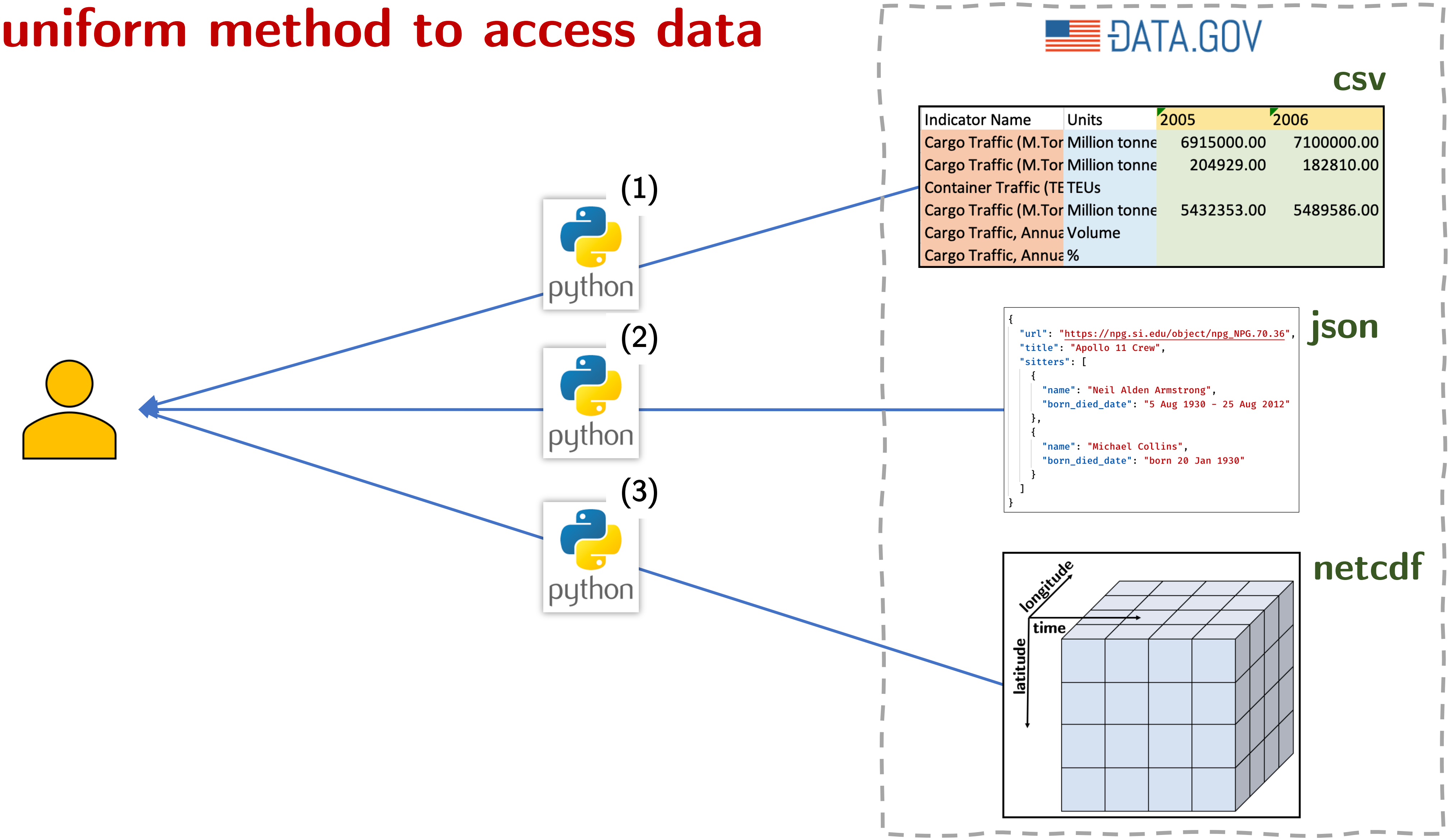
D-REPR: A Language For Describing And Mapping Diversely-Structured Data Sources To RDF

Binh Vu, Jay Pujara, and Craig Knoblock

Motivating example

No uniform method to access data

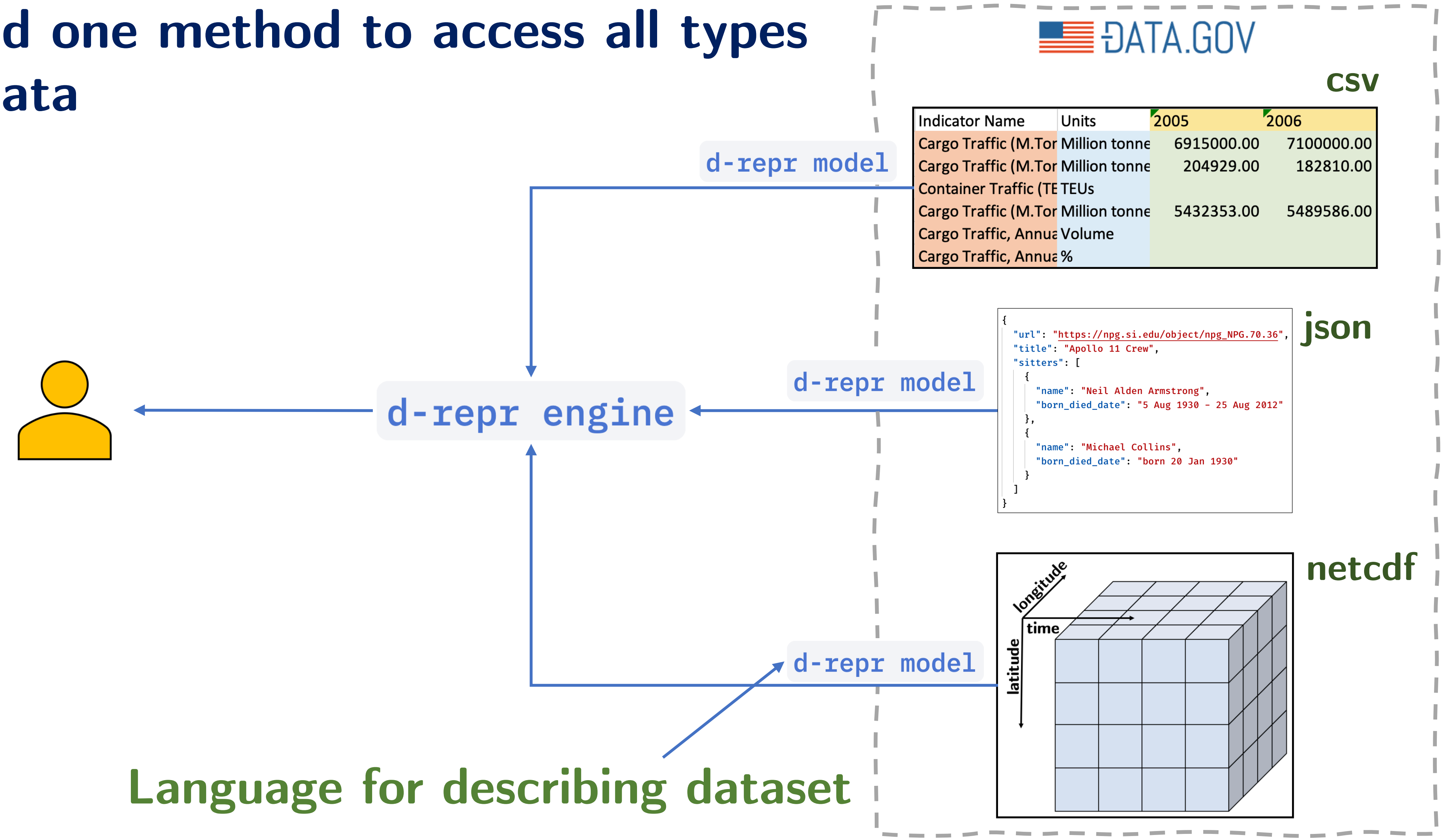


Indicator Name	Units	2005	2006
Cargo Traffic (M.Tor	Million tonne	6915000.00	7100000.00
Cargo Traffic (M.Tor	Million tonne	204929.00	182810.00
Container Traffic (TE	TEUs		
Cargo Traffic (M.Tor	Million tonne	5432353.00	5489586.00
Cargo Traffic, Annua	Volume		
Cargo Traffic, Annua	%		

```
{
  "url": "https://npg.si.edu/object/npg_NPG.70.36",
  "title": "Apollo 11 Crew",
  "sitters": [
    {
      "name": "Neil Alden Armstrong",
      "born_died_date": "5 Aug 1930 - 25 Aug 2012"
    },
    {
      "name": "Michael Collins",
      "born_died_date": "born 20 Jan 1930"
    }
  ]
}
```

Motivating example

Need one method to access all types of data



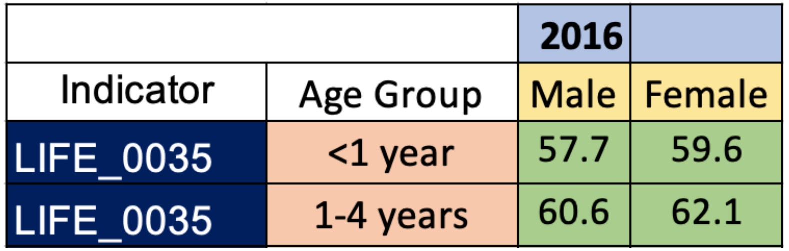
Indicator Name	Units	2005	2006
Cargo Traffic (M.Tor	Million tonne	6915000.00	7100000.00
Cargo Traffic (M.Tor	Million tonne	204929.00	182810.00
Container Traffic (TE	TEUs		
Cargo Traffic (M.Tor	Million tonne	5432353.00	5489586.00
Cargo Traffic, Annua	Volume		
Cargo Traffic, Annua	%		

```json
{
  "url": "https://npg.si.edu/object/npg_NPG.70.36",
  "title": "Apollo 11 Crew",
  "sitters": [
    {
      "name": "Neil Alden Armstrong",
      "born_died_date": "5 Aug 1930 - 25 Aug 2012"
    },
    {
      "name": "Michael Collins",
      "born_died_date": "born 20 Jan 1930"
    }
  ]
}
```

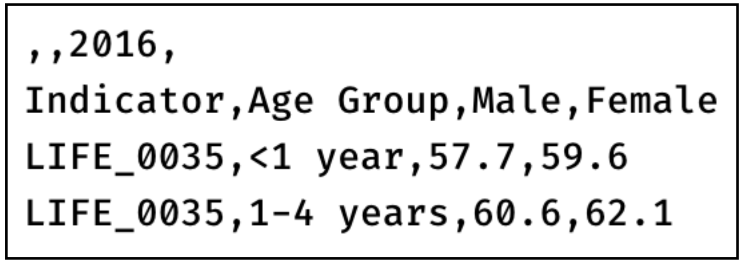
Language for describing dataset

Heterogeneous datasets

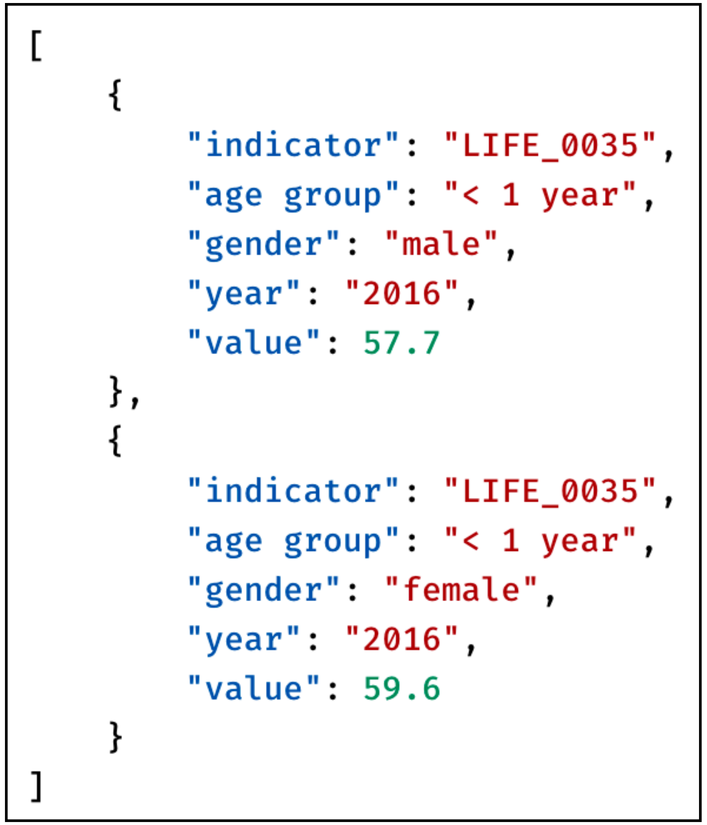
- Multiple **formats**: CSV, JSON, XLSX, NetCDF4, …



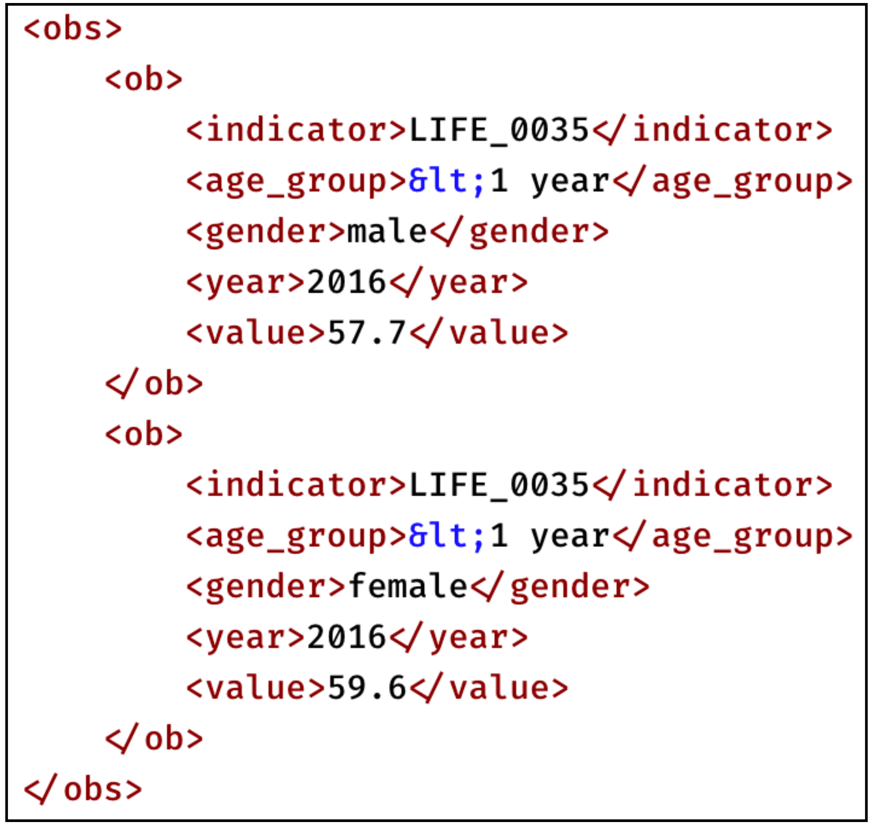
		2016	
Indicator	Age Group	Male	Female
LIFE_0035	<1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1



```
,,2016,
Indicator,Age Group,Male,Female
LIFE_0035,<1 year,57.7,59.6
LIFE_0035,1-4 years,60.6,62.1
```



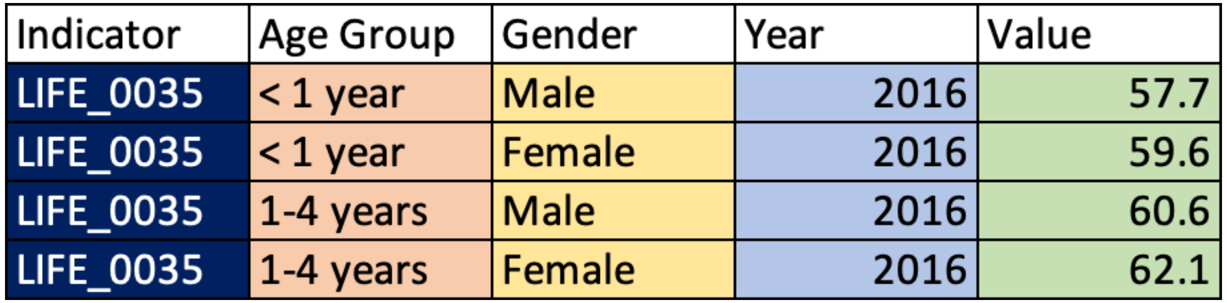
```
[
    {
        "indicator": "LIFE_0035",
        "age group": "< 1 year",
        "gender": "male",
        "year": "2016",
        "value": 57.7
    },
    {
        "indicator": "LIFE_0035",
        "age group": "< 1 year",
        "gender": "female",
        "year": "2016",
        "value": 59.6
    }
]
```



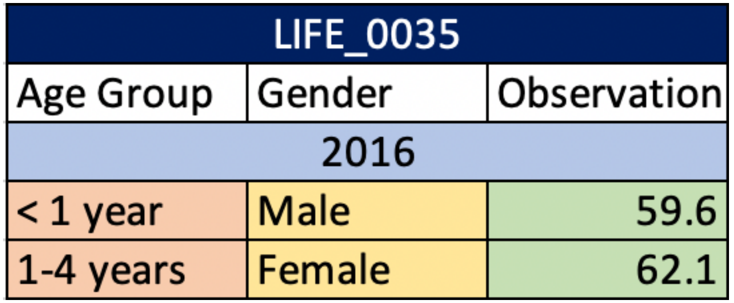
```
<obs>
    <ob>
        <indicator>LIFE_0035</indicator>
        <age_group>&lt;1 year</age_group>
        <gender>male</gender>
        <year>2016</year>
        <value>57.7</value>
    </ob>
    <ob>
        <indicator>LIFE_0035</indicator>
        <age_group>&lt;1 year</age_group>
        <gender>female</gender>
        <year>2016</year>
        <value>59.6</value>
    </ob>
</obs>
```

Heterogeneous datasets

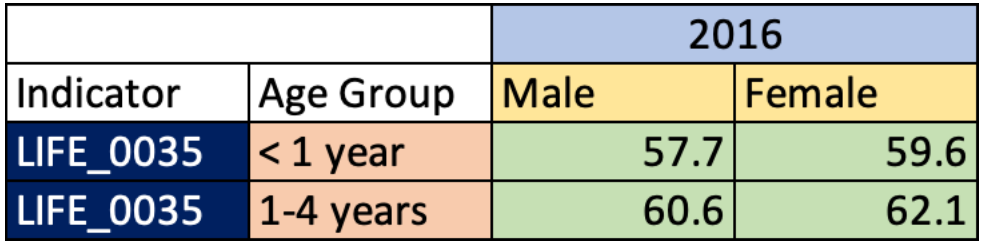
- Same format, multiple **layouts**



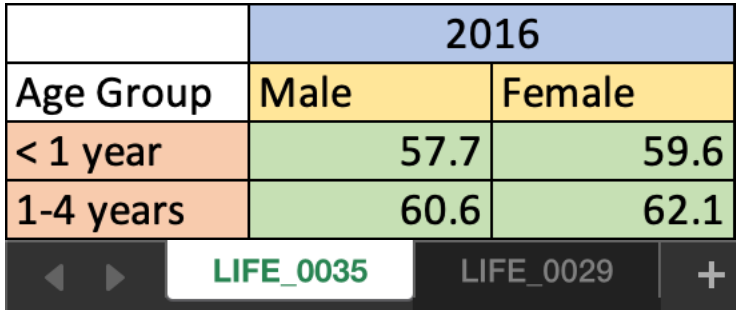
Indicator	Age Group	Gender	Year	Value
LIFE_0035	< 1 year	Male	2016	57.7
LIFE_0035	< 1 year	Female	2016	59.6
LIFE_0035	1-4 years	Male	2016	60.6
LIFE_0035	1-4 years	Female	2016	62.1



LIFE_0035		
Age Group	Gender	Observation
2016		
< 1 year	Male	59.6
1-4 years	Female	62.1



		2016	
Indicator	Age Group	Male	Female
LIFE_0035	< 1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1



	2016	
Age Group	Male	Female
< 1 year	57.7	59.6
1-4 years	60.6	62.1

Related work

- Mapping nested relational datasets:
  - RML (Dimou et al, 2014), KR2RML (Slepicka et al 2015), xR2RML (Michel et al, 2015), etc.
  - Can handle multiple **formats** but only work for nested relational model layout

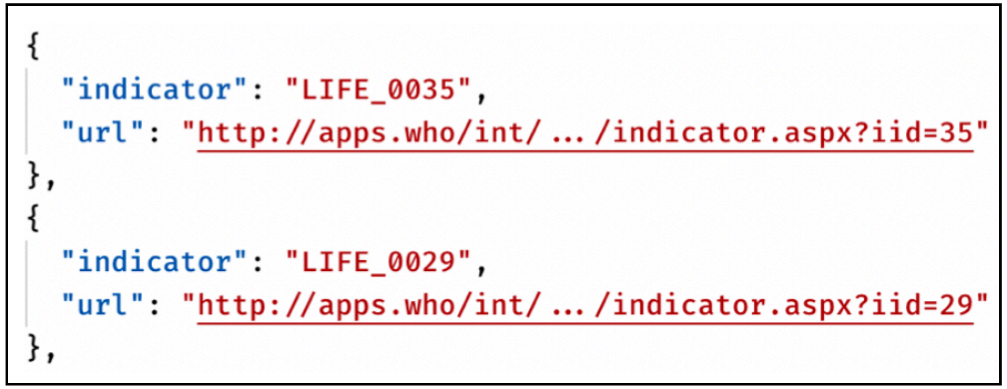
- Mapping tabular datasets:
  - XLWrap (Langegger et al, 2009), M2 (O'Connor et al, 2010), T2WML (Szekely et al, 2019)
  - Can handle multiple **layouts**, but support only **tabular formats**

Contributions

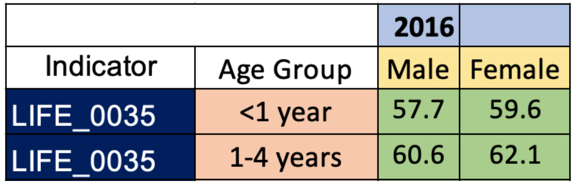
- A generic language to easily for describing and mapping heterogeneous datasets to RDF
  - It's capable of mapping wide variety of data sources and goes beyond the set of sources that existing languages support.
- The language is extensible to new formats and layouts
- An efficient engine to convert datasets to RDF

Our approach

Step 1: define resources

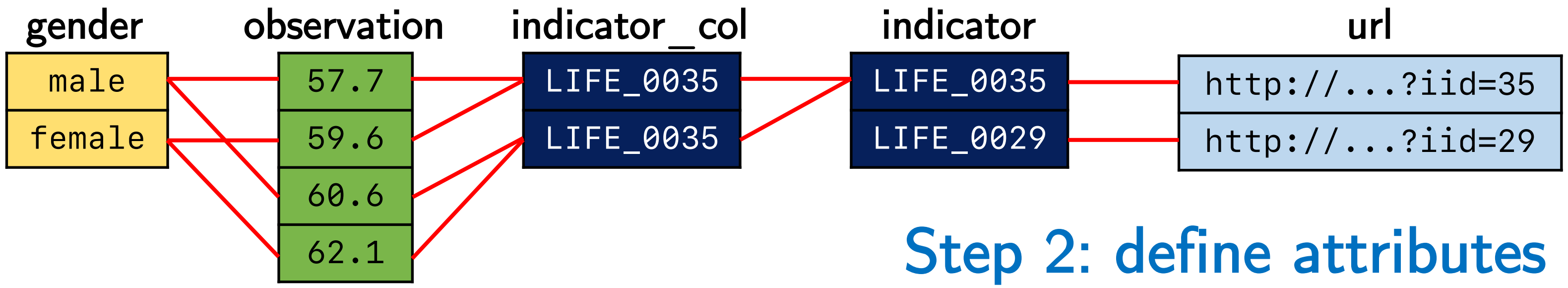


```
{
  "indicator": "LIFE_0035",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=35"
},
{
  "indicator": "LIFE_0029",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=29"
},
```



		2016	
Indicator	Age Group	Male	Female
LIFE_0035	<1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1

Step 2: define attributes



gender: male, female

observation: 57.7, 59.6, 60.6, 62.1

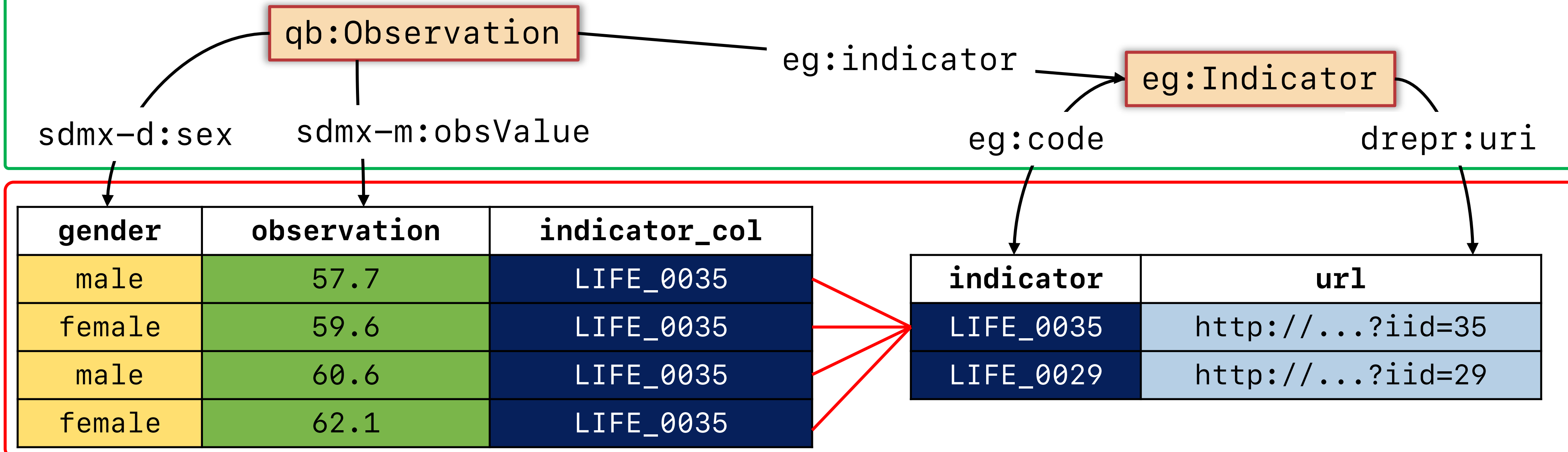
indicator_col: LIFE_0035, LIFE_0035

indicator: LIFE_0035, LIFE_0029

url: http://...?iid=35, http://...?iid=29

Step 4: semantic modeling

Step 3: join attributes to tables

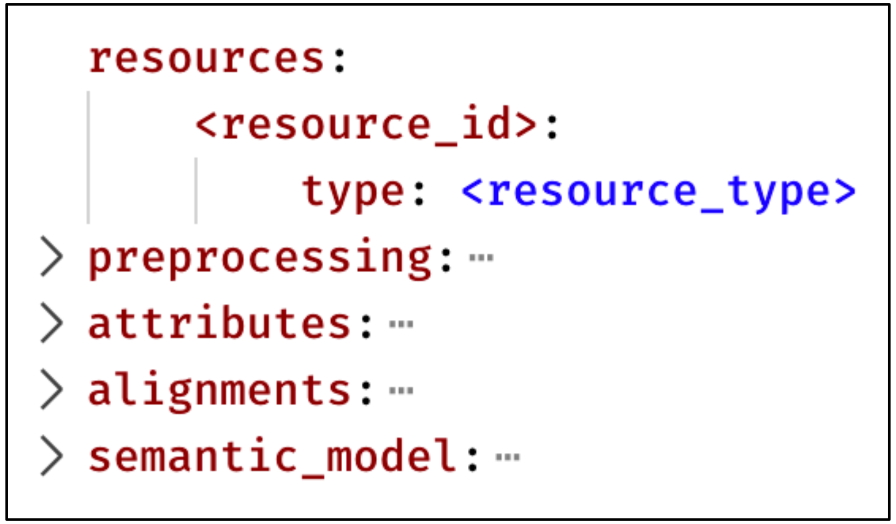


gender	observation	indicator_col
male	57.7	LIFE_0035
female	59.6	LIFE_0035
male	60.6	LIFE_0035
female	62.1	LIFE_0035

indicator	url
LIFE_0035	http://...?iid=35
LIFE_0029	http://...?iid=29

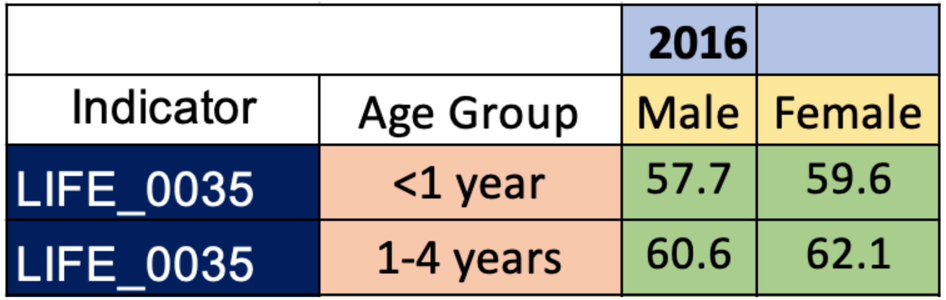
Step 1: Resources

- A resource can be a physical file, SQL table, etc.
- Syntax:



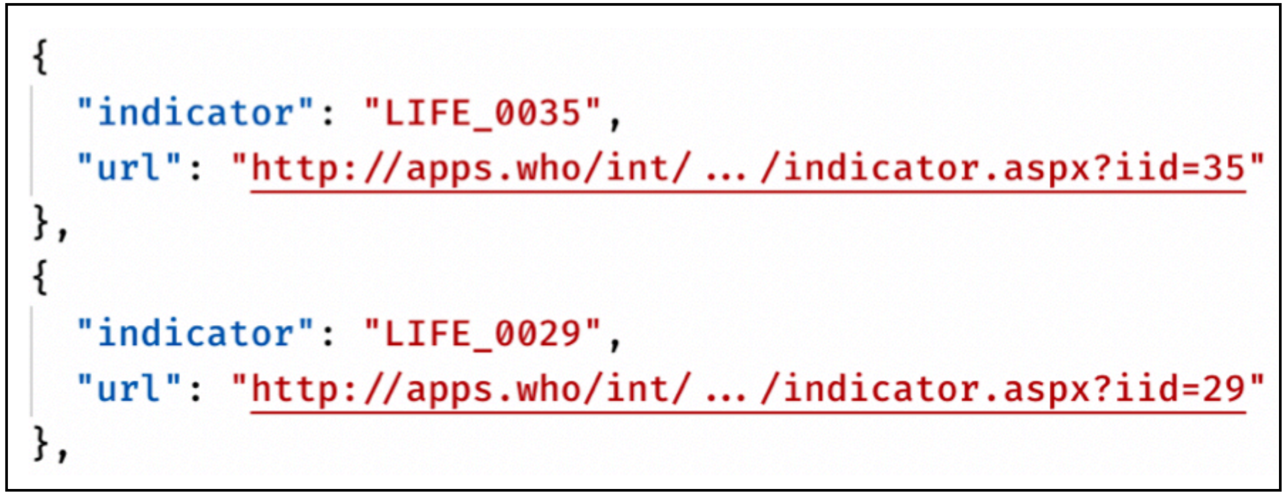
```
resources:
    <resource_id>:
        type: <resource_type>
preprocessing: …
attributes: …
alignments: …
semantic_model: …
```

life_table.csv



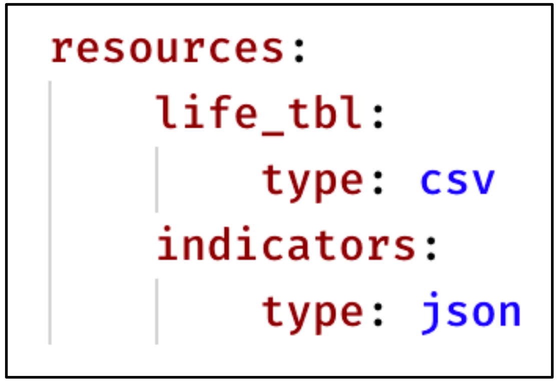
		2016	
Indicator	Age Group	Male	Female
LIFE_0035	<1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1

indicators.json



```
{
  "indicator": "LIFE_0035",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=35"
},
{
  "indicator": "LIFE_0029",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=29"
},
```

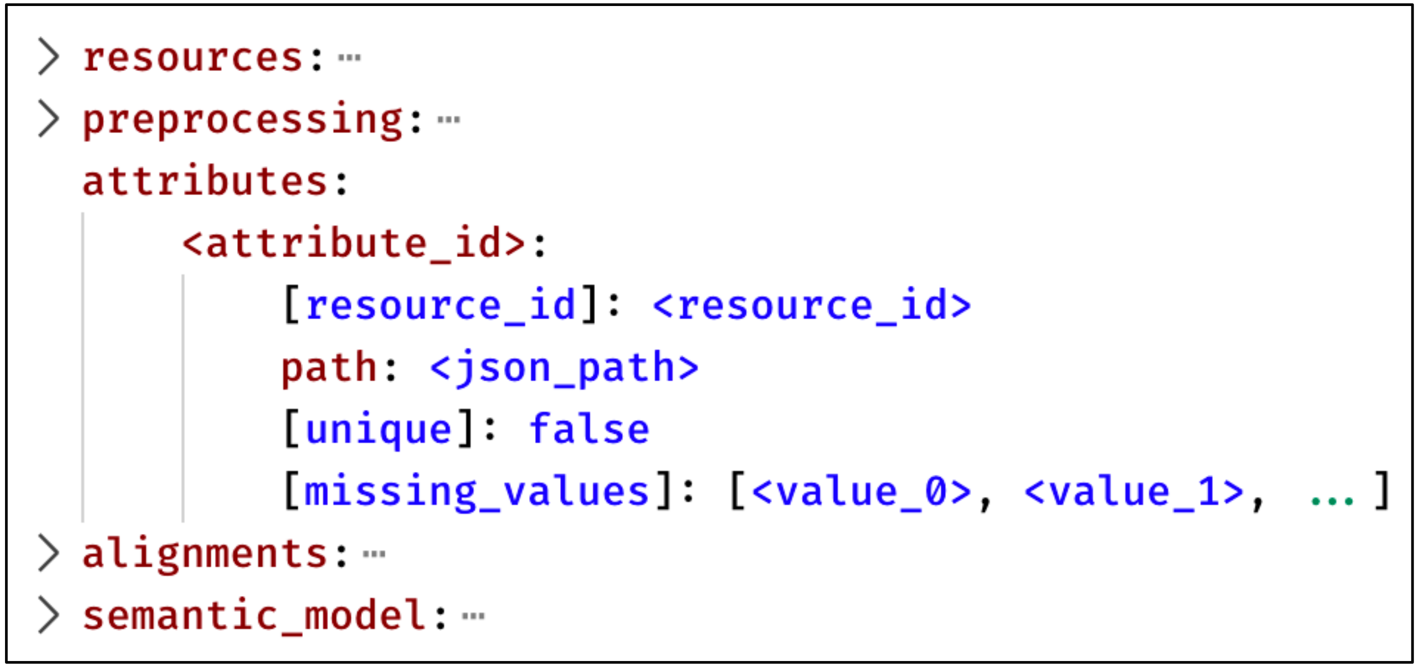
- Example:



```
resources:
    life_tbl:
        type: csv
    indicators:
        type: json
```

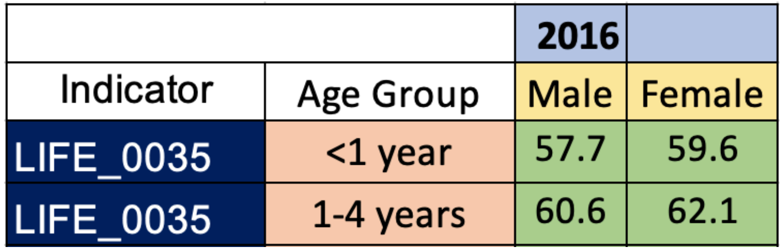
Step 2: Attributes

- Containing values that belong to a group
- Syntax

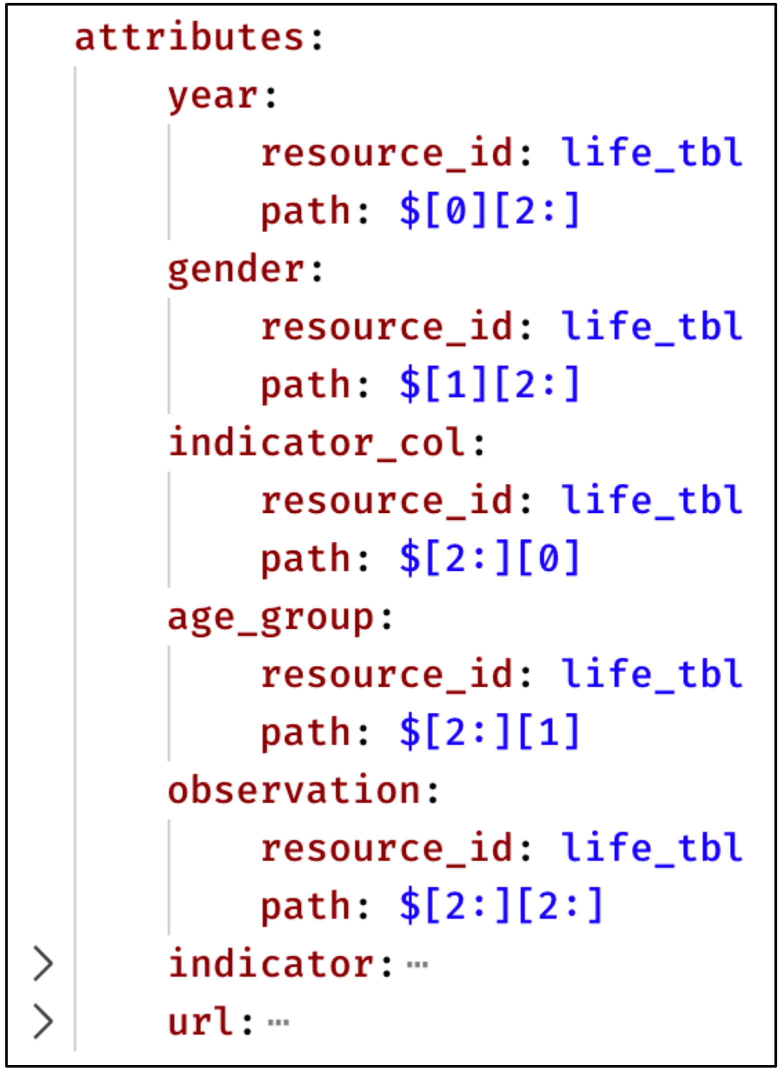


```
resources: …
preprocessing: …
attributes:
    <attribute_id>:
        [resource_id]: <resource_id>
        path: <json_path>
        [unique]: false
        [missing_values]: [<value_0>, <value_1>,  … ]
alignments: …
semantic_model: …
```

life_table.csv



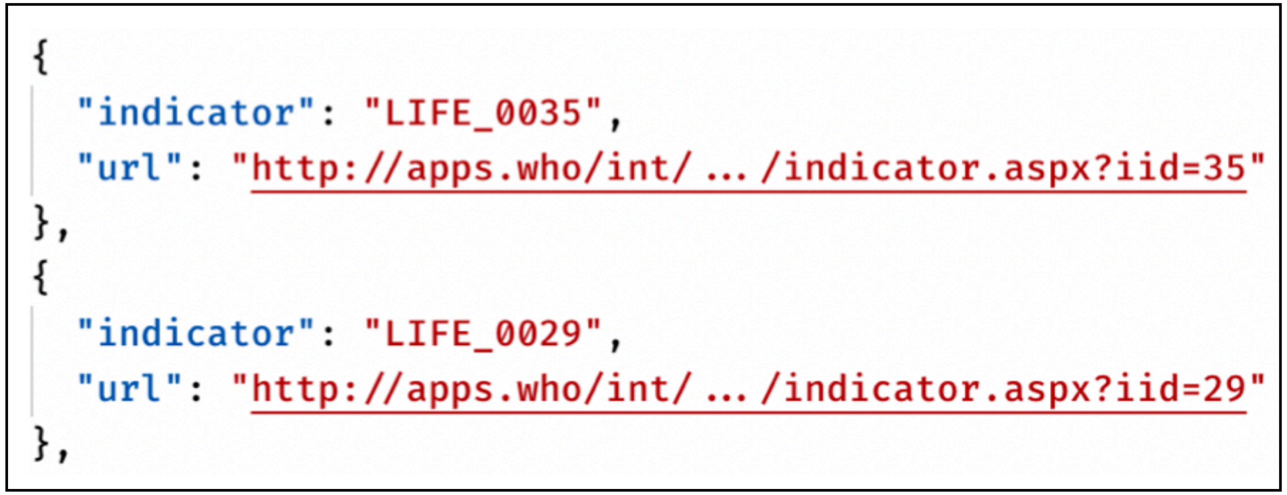
		2016	
Indicator	Age Group	Male	Female
LIFE_0035	<1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1



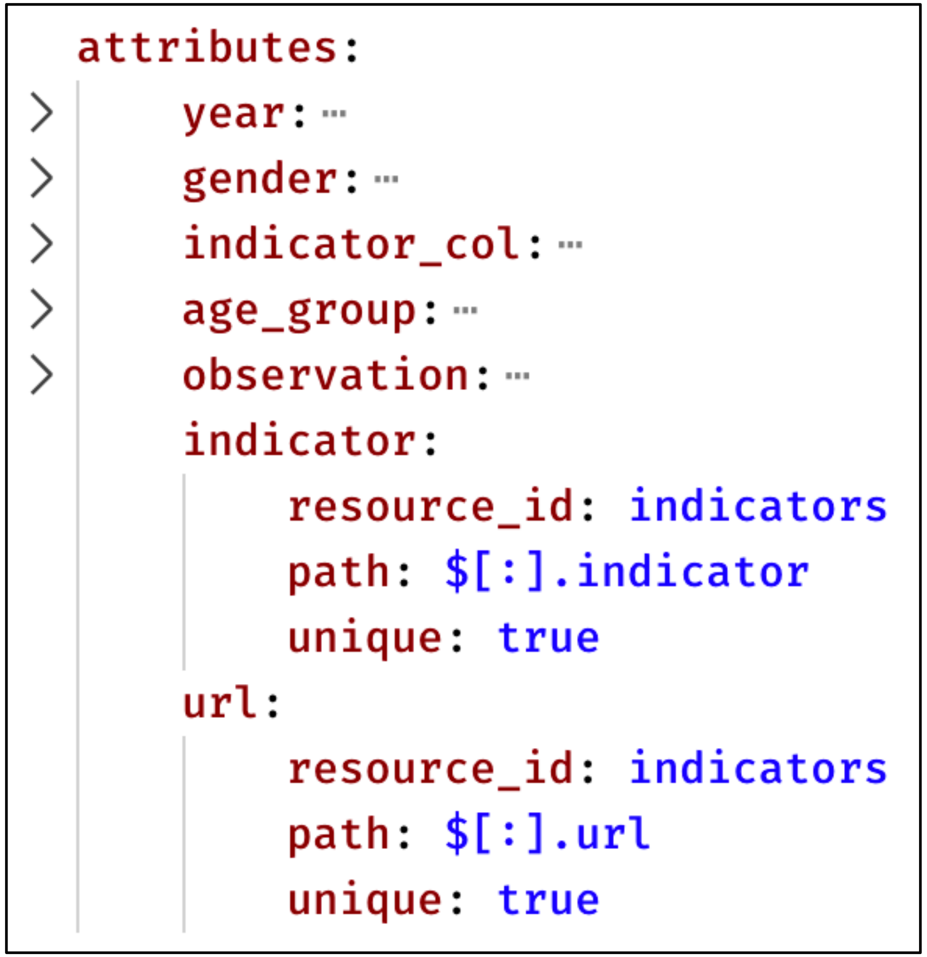
```
attributes:
    year:
        resource_id: life_tbl
        path: $[0][2:]
    gender:
        resource_id: life_tbl
        path: $[1][2:]
    indicator_col:
        resource_id: life_tbl
        path: $[2:][0]
    age_group:
        resource_id: life_tbl
        path: $[2:][1]
    observation:
        resource_id: life_tbl
        path: $[2:][2:]
    indicator: …
    url: …
```

Step 2: Attributes

indicators.json



```
{
  "indicator": "LIFE_0035",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=35"
},
{
  "indicator": "LIFE_0029",
  "url": "http://apps.who/int/ … /indicator.aspx?iid=29"
},
```

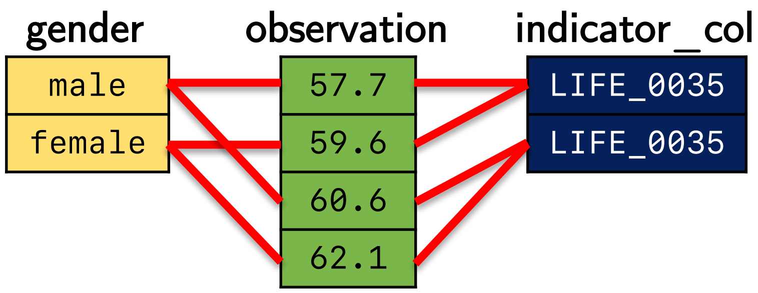


```
attributes:
    year: ⋯
    gender: ⋯
    indicator_col: ⋯
    age_group: ⋯
    observation: ⋯
    indicator:
        resource_id: indicators
        path: $[:].indicator
        unique: true
    url:
        resource_id: indicators
        path: $[:].url
        unique: true
```

Step 3: Alignments

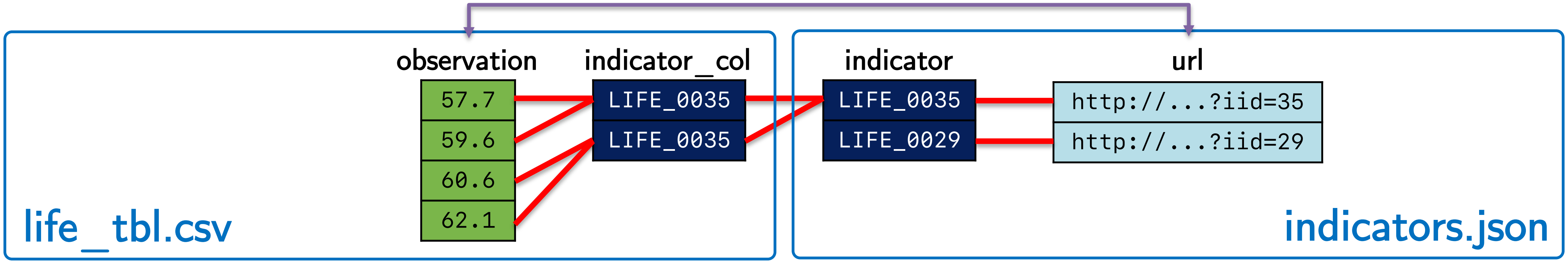
- Explicitly specifying the layout through alignments

Indicator	male	female
LIFE_0035	57.7	59.6
LIFE_0035	60.6	62.1



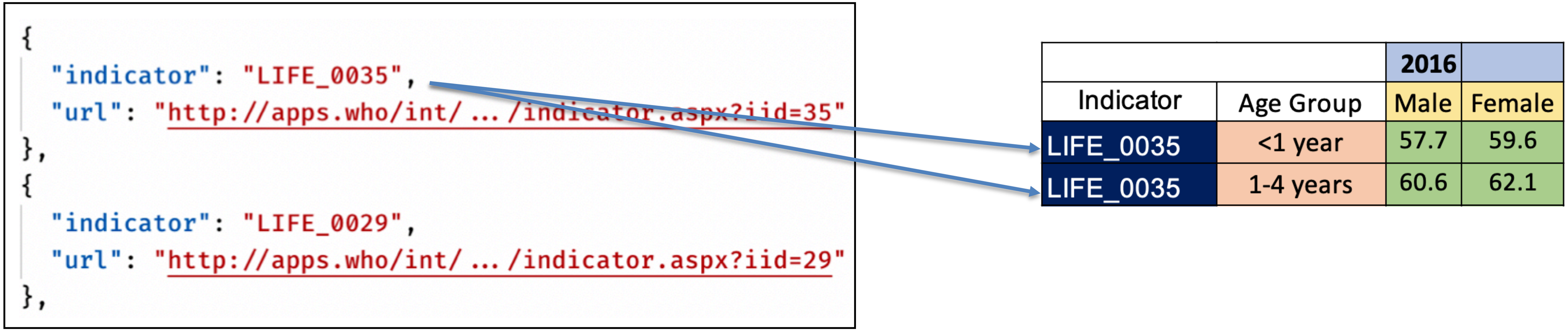
gender	observation	indicator_col
male	57.7	LIFE_0035
female	59.6	LIFE_0035
male	60.6	LIFE_0035
female	62.1	LIFE_0035

- For linking across resources



Step 3: Alignments

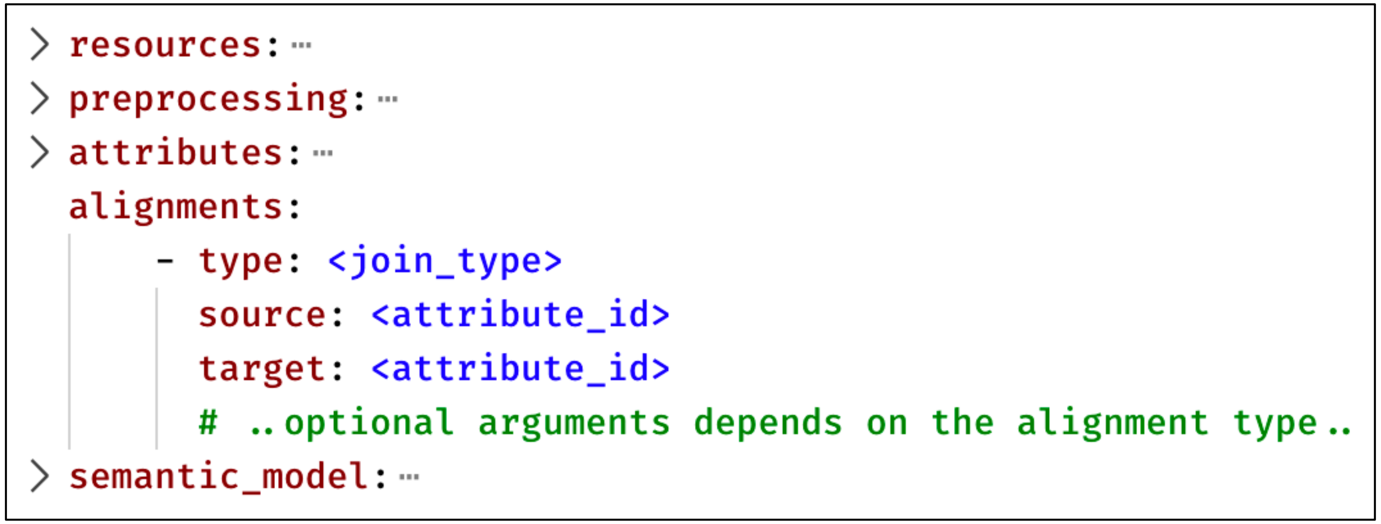
- Join by value (equi-join)



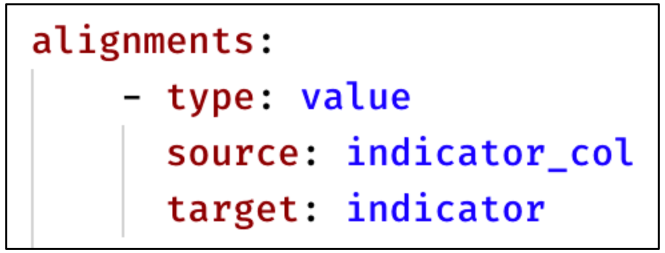
```
{
  "indicator": "LIFE_0035",
  "url": "http://apps.who/int/ ... /indicator.aspx?iid=35"
},
{
  "indicator": "LIFE_0029",
  "url": "http://apps.who/int/ ... /indicator.aspx?iid=29"
},
```

		2016	
Indicator	Age Group	Male	Female
LIFE_0035	<1 year	57.7	59.6
LIFE_0035	1-4 years	60.6	62.1

- Syntax



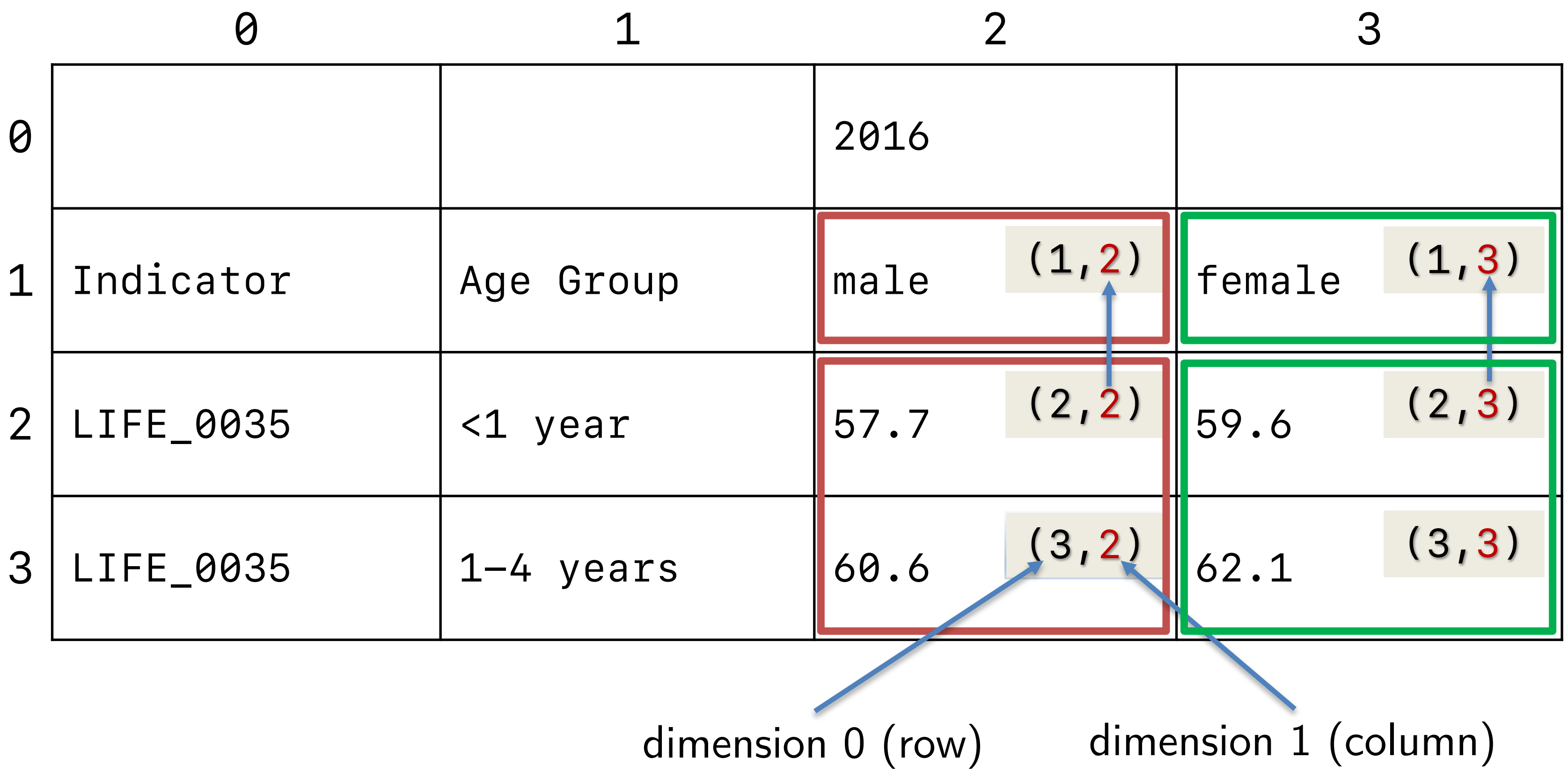
```
> resources: ⋯
> preprocessing: ⋯
> attributes: ⋯
  alignments:
      - type: <join_type>
        source: <attribute_id>
        target: <attribute_id>
        # ..optional arguments depends on the alignment type..
> semantic_model: ⋯
```



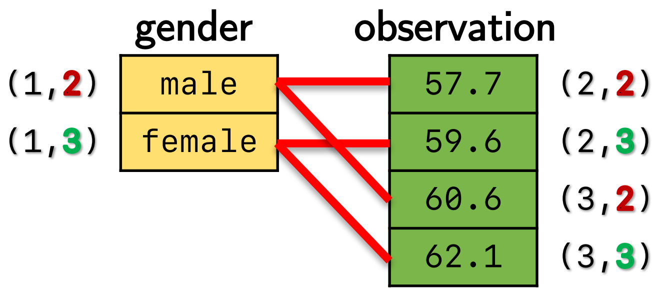
```
alignments:
    - type: value
      source: indicator_col
      target: indicator
```

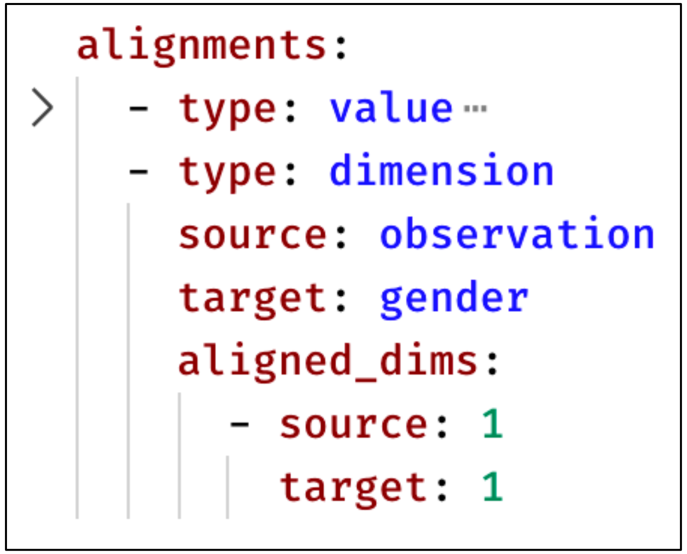
Step 3: Alignments

- Join by positions in the dataset



	0	1	2	3
0			2016	
1	Indicator	Age Group	male (1,2)	female (1,3)
2	LIFE_0035	<1 year	57.7 (2,2)	59.6 (2,3)
3	LIFE_0035	1–4 years	60.6 (3,2)	62.1 (3,3)

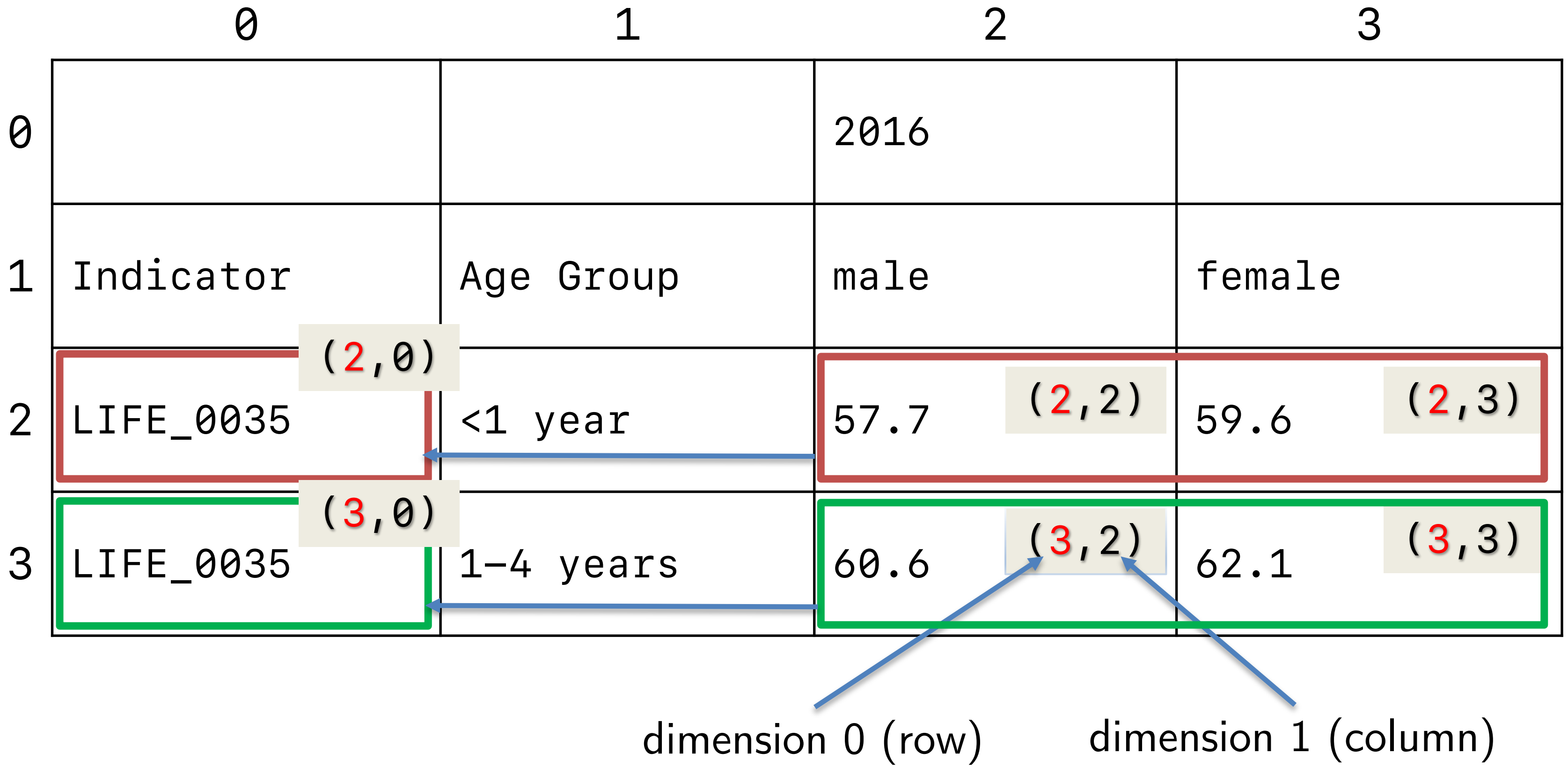




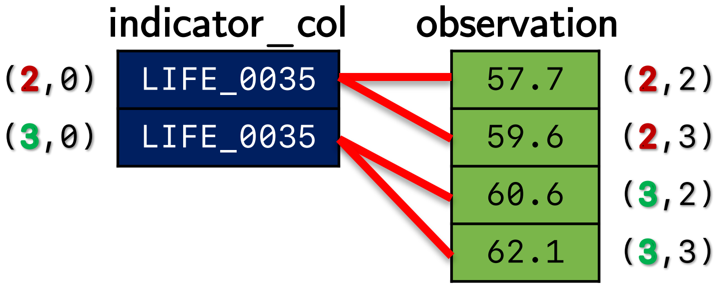
```
alignments:
  - type: value ⋯
  - type: dimension
    source: observation
    target: gender
    aligned_dims:
      - source: 1
        target: 1
```

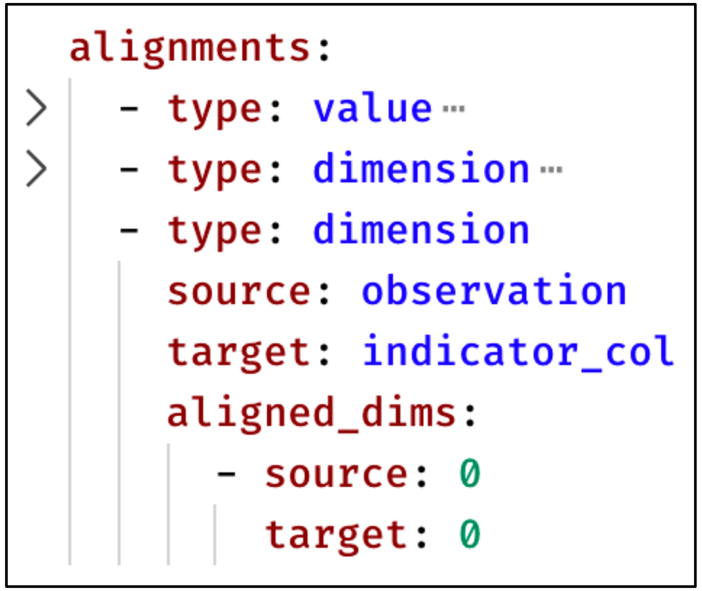
Step 3: Alignments

- Join by positions in the dataset



	0	1	2	3
0			2016	
1	Indicator	Age Group	male	female
2	LIFE_0035 (2,0)	<1 year	57.7 (2,2)	59.6 (2,3)
3	LIFE_0035 (3,0)	1–4 years	60.6 (3,2)	62.1 (3,3)

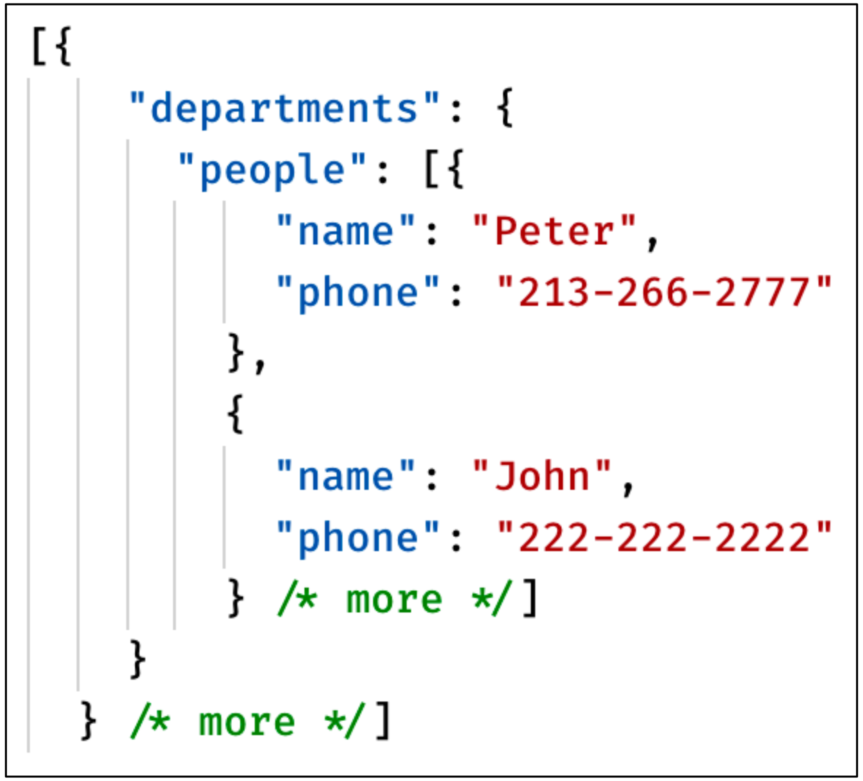




```
alignments:
  - type: value ...
  - type: dimension ...
  - type: dimension
    source: observation
    target: indicator_col
    aligned_dims:
      - source: 0
        target: 0
```

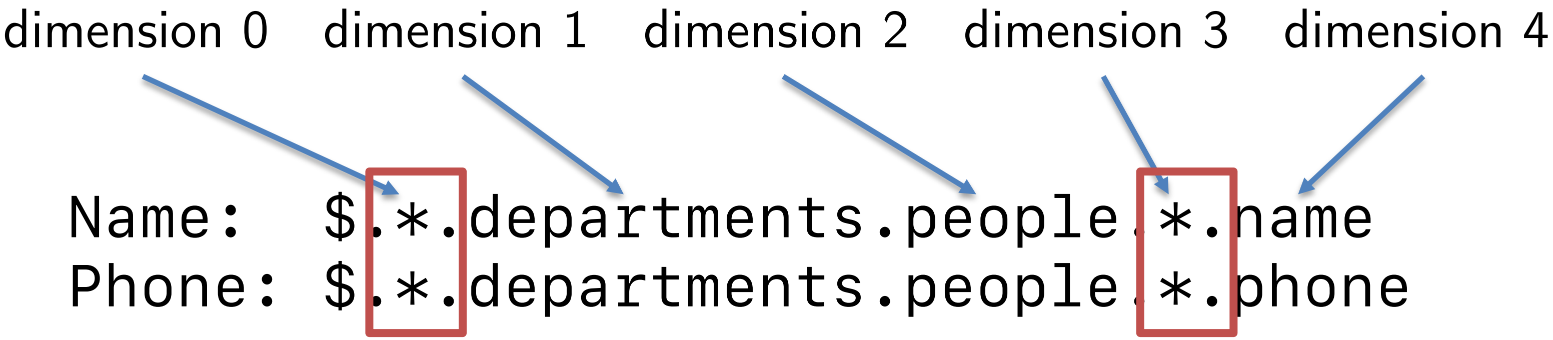
Step 3: Alignments

- Join by positions in the dataset



```
[{
    "departments": {
      "people": [{
          "name": "Peter",
          "phone": "213-266-2777"
        },
        {
          "name": "John",
          "phone": "222-222-2222"
        } /* more */]
    }
  } /* more */]
```

Sample data



dimension 0 dimension 1 dimension 2 dimension 3 dimension 4

```
Name:   $.*.departments.people.*.name
Phone:  $.*.departments.people.*.phone
```

Aligned in dimensions 0 and 3

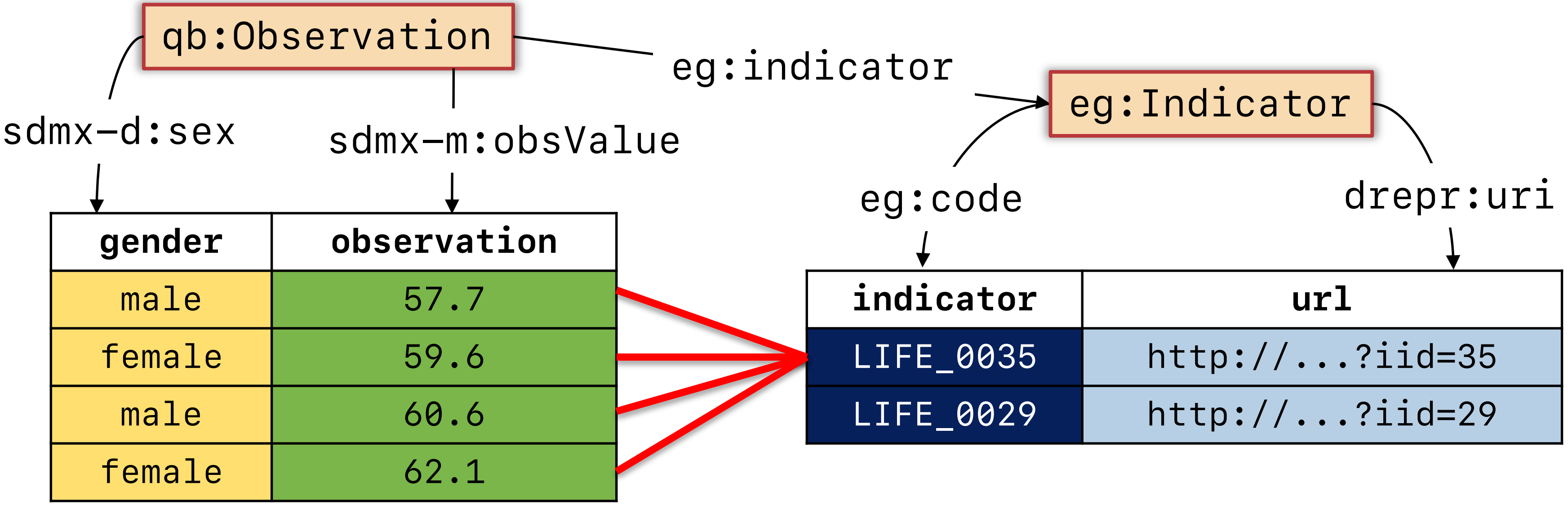
Step 3: Alignments

- Easy to incorporate new alignment function

- Users only need to define the minimum number of joins (N-1) because the engine can infer the rest via composition.

Step 4: Semantic Model

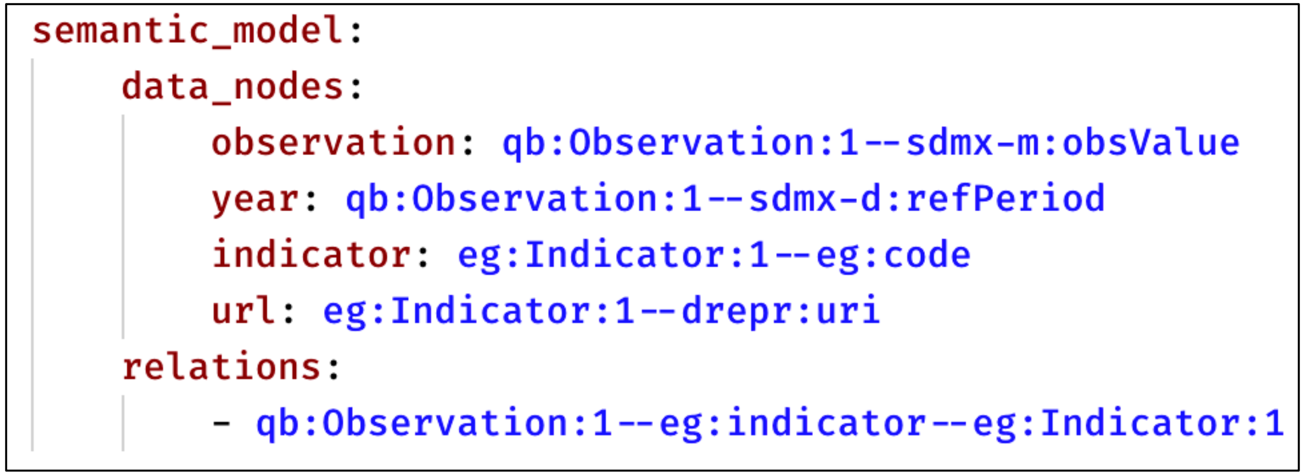
- Using ontologies to describe your data (classes and predicates)



gender	observation
male	57.7
female	59.6
male	60.6
female	62.1

indicator	url
LIFE_0035	http://...?iid=35
LIFE_0029	http://...?iid=29

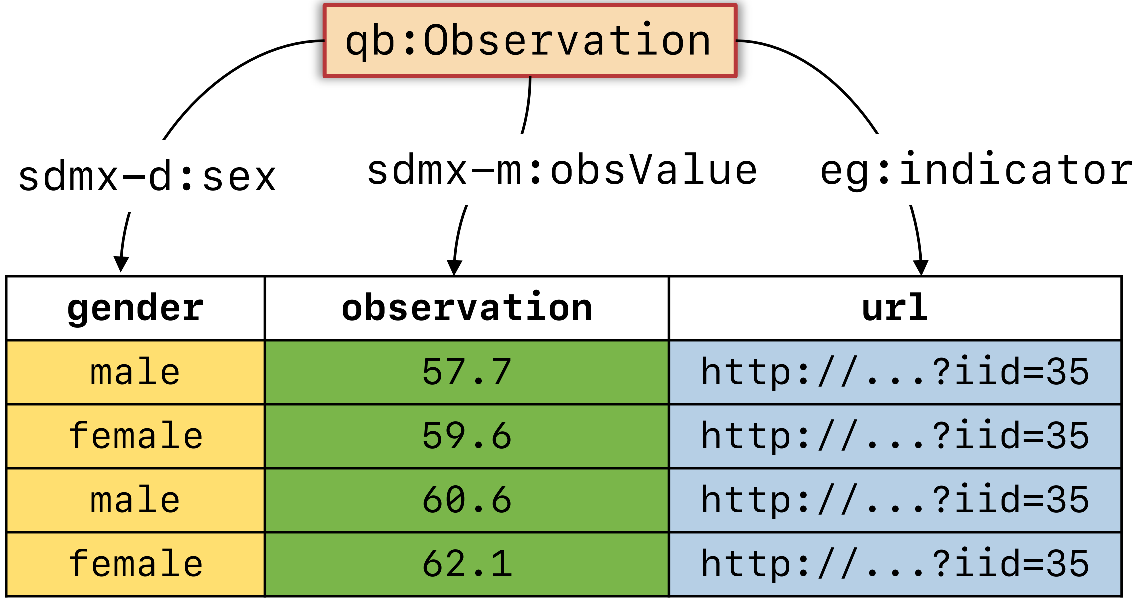
- Syntax



```
semantic_model:
    data_nodes:
        observation: qb:Observation:1--sdmx-m:obsValue
        year: qb:Observation:1--sdmx-d:refPeriod
        indicator: eg:Indicator:1--eg:code
        url: eg:Indicator:1--drepr:uri
    relations:
        - qb:Observation:1--eg:indicator--eg:Indicator:1
```

Step 4: Semantic Model

- Users can create arbitrary semantic model, even when using attributes across multiple resources



qb:Observation

sdmx-d:sex

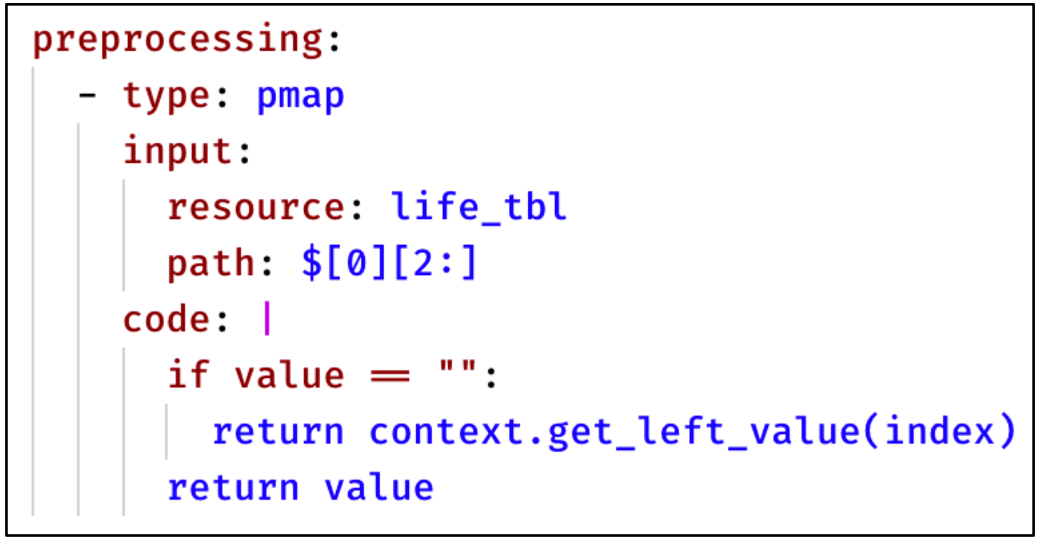
sdmx-m:obsValue

eg:indicator

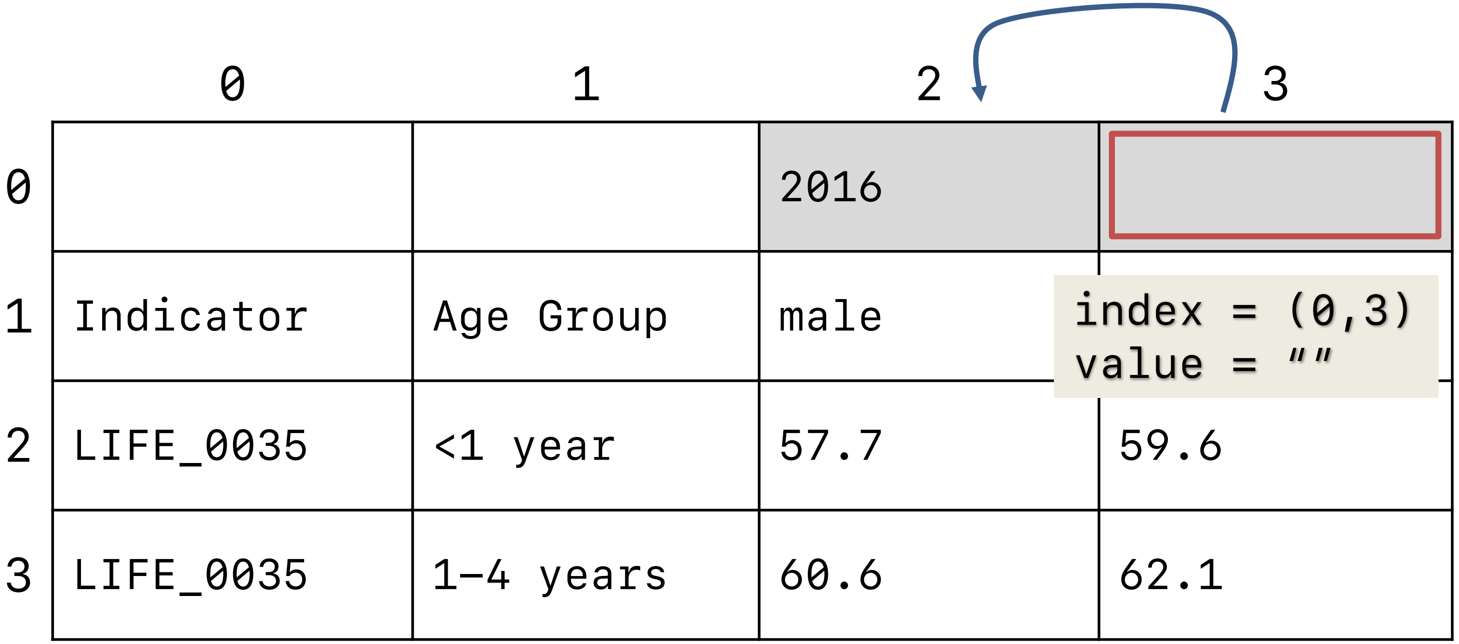
gender	observation	url
male	57.7	http://...?iid=35
female	59.6	http://...?iid=35
male	60.6	http://...?iid=35
female	62.1	http://...?iid=35

Data cleaning (optional)

- Users can write python function to clean or transform the data



```
preprocessing:
  - type: pmap
    input:
      resource: life_tbl
      path: $[0][2:]
    code: |
      if value == "":
        return context.get_left_value(index)
      return value
```



	0	1	2	3
0			2016	
1	Indicator	Age Group	male	
2	LIFE_0035	<1 year	57.7	59.6
3	LIFE_0035	1–4 years	60.6	62.1

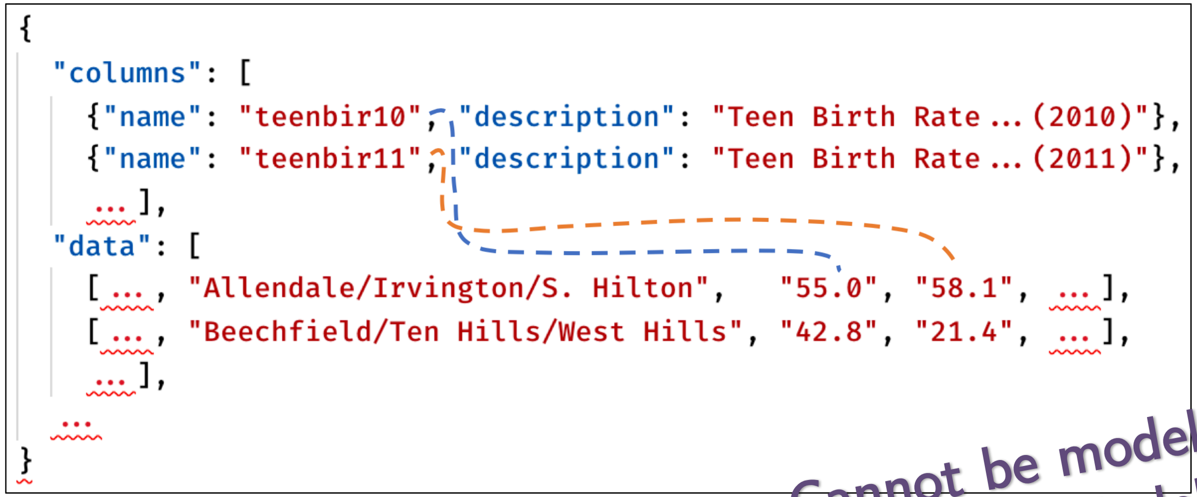
index = (0,3)
value = ""

- Can re-use functions or existing libraries

Evaluation

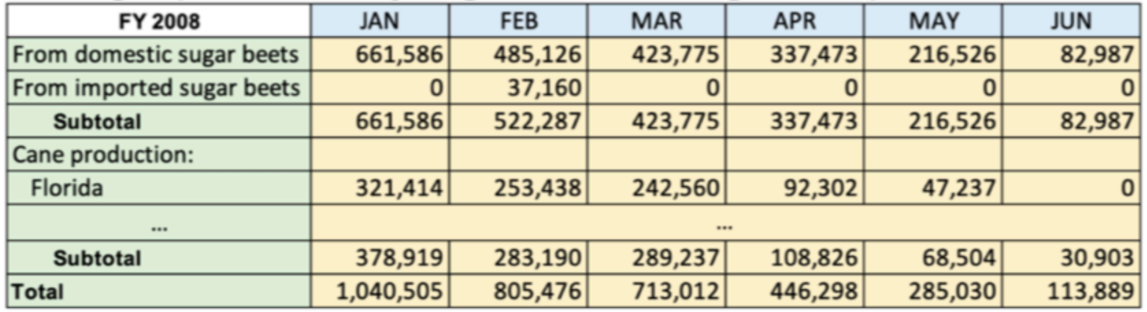
- Coverage of D-REPR
  - Randomly sampling 700 datasets from data.gov
  - Modeling datasets of different formats and layouts

a. Children and Family Health



```
{
  "columns": [
    {"name": "teenbir10", "description": "Teen Birth Rate ... (2010)"},
    {"name": "teenbir11", "description": "Teen Birth Rate ... (2011)"},
    ... ],
  "data": [
    [ ... , "Allendale/Irvington/S. Hilton",   "55.0", "58.1",  ... ],
    [ ... , "Beechfield/Ten Hills/West Hills", "42.8", "21.4",  ... ],
    ... ],
  ...
}
```

b. Sugar production by sugar beet and sugarcane processors

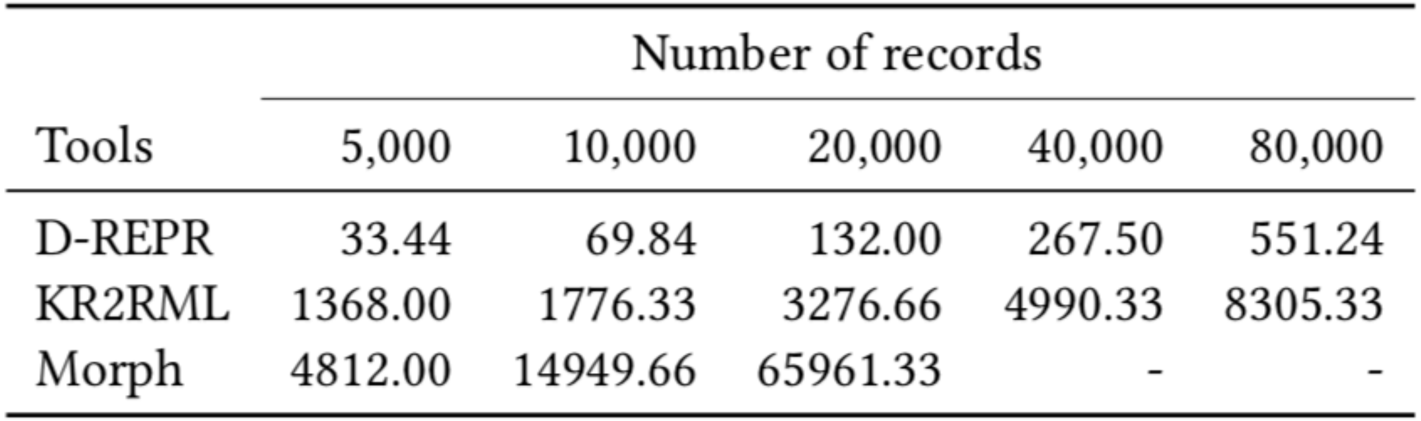


FY 2008	JAN	FEB	MAR	APR	MAY	JUN
From domestic sugar beets	661,586	485,126	423,775	337,473	216,526	82,987
From imported sugar beets	0	37,160	0	0	0	0
Subtotal	661,586	522,287	423,775	337,473	216,526	82,987
Cane production:						
Florida	321,414	253,438	242,560	92,302	47,237	0
...	...					
Subtotal	378,919	283,190	289,237	108,826	68,504	30,903
Total	1,040,505	805,476	713,012	446,298	285,030	113,889

Cannot be modeled with Nested Relational Models!

Evaluation

- Runtime of D-REPR engine (ms)
  - Mapping large CSV files (row-based table) containing (name, phone, address)
  - Generating 1.3m triples / second (15 times faster than KR2RML)



	Number of records				
Tools	5,000	10,000	20,000	40,000	80,000
D-REPR	33.44	69.84	132.00	267.50	551.24
KR2RML	1368.00	1776.33	3276.66	4990.33	8305.33
Morph	4812.00	14949.66	65961.33	-	-

Discussion and Future work

- A novel **generic** data representation language: D-REPR
  - Uses a declarative approach
  - Works for heterogeneous datasets of different formats and layouts
- Open source: https://github.com/usc-isi-i2/d-repr
- Future work:
  - (Semi-)automatically generating D-REPR models
  - UI for annotating datasets
  - Improving efficiency of D-REPR's engine by doing parallel processing

References

- [1] RML: Anastasia Dimou, Miel Vander Sande, Pieter Colpaert, Ruben Verborgh, Erik Mannens, and Rik Van de Walle. 2014. RML: A Generic Language for Integrated RDF Mappings of Heterogeneous Data
- [2] KR2RML: Jason Slepicka, Chengye Yin, Pedro Szekely, and Craig A. Knoblock. 2015. KR2RML: An Alternative Interpretation of R2RML for Heterogenous Sources
- [3] xR2RML: Franck Michel, Loïc Djimenou, Catherine Faron Zucker, and Johan Montagnat. 2015. Translation of relational and non-relational databases into RDF with xR2RML
- [4] XLWrap: Andreas Langegger and Wolfram Wöß. 2009. XLWrap — Querying and Inte- grating Arbitrary Spreadsheets with SPARQL
- [5] Martin J O'Connor, Christian Halaschek-Wiener, and Mark A Musen. 2010. M2: A Language for Mapping Spreadsheets to OWL