A Healthcare Ontology for Global City Indicators (ISO 37120)

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Abstract

This paper presents an ontology to describe the Healthcare indicators within the ISO 37120 standard. The objective of this representation is to automate the analysis of healthcare indicators and the performance on the indicators, in cities around the world. This representation gives us the ability to not only represent the ontology but more importantly, it provides a representation and a precise definition of the health indicators within ISO 37120. This approach to representing indicators reduces ambiguity, ensures consistency of metrics and helps achieve interoperability.

Several ontologies have been created to help define and represent the healthcare indicators, including 'Licensure' and 'Healthcare Professional'.

Keywords: Health Ontology, City Indicator, Semantic Web, ISO 37120

1. Introduction

We define an ontology for the representation of Health theme indicators for ISO 37120. ISO 37120 has been developed to help cities assess the performance of city services, service provisions as well as the quality of life (ISO, 2014). The standard is a collection of 100 city indicators with a definition and methodology provided for each indicator.

This paper is one of a series – as part of the PolisGnosis Project (Fox, 2015a) - that seeks to formalize the representation of city data and knowledge (Fox, 2013; Fox, 2015b; Forde & Fox, 2015; Wang & Fox; 2015). In particular, the goal of this paper is to:

1. Define a healthcare ontology that enables the definition of ISO 37120 health indicators,

2. Provide a computationally precise definition for each ISO 37120 health theme indicator, based on the GCI foundation and healthcare ontologies,
3. Publish the ISO 37120 Health indicator definitions using semantic web standards, thereby making it possible to reason about the definitions and instances using existing ontology tools, and
4. Enable the automated analysis of city indicators.

This paper will begin by reviewing the definitions of the health indicators as defined in ISO 37120. For each indicator, we will describe several competency questions that the ontology must be able to answer. The process of defining competency questions is iterative and the questions themselves may be modified to account for changes in the indicators or even the addition of new indicators to the standard. Competency questions here will be classified into four categories; factual, definitional, internally consistent or deduced. We will also review existing ontologies that may potentially be equipped to answer the competency questions outlined earlier. We will then outline the class and property requirements for each indicator to ensure they satisfy the competency questions.

2. Indicators and their Competency Requirements

Following the ontology development process of Gruninger & Fox (1995), we will define competency questions that specify the representational requirements for each ISO 37120 indicator. According to (Fox, 2014), competency questions can be categorized as follows:

1. **Factual (F)**: Questions that query the value of some property.
2. **Consistency-Definitional** (CD) Questions that determine whether the instantiation of an indicator by a city are consistent with each other.
3. **Consistency-Internal (CI)**: Questions that determine whether different parts of the instantiation are consistent with each other.
4. **Deduced (D)**: A value or relationship that can be deduced from the instantiation.

In the remainder of this section, for each ISO 37120 health theme indicator, we will provide its definition, as found in the standard, followed by a set of competency questions.

2.1. ISO 37120 12.1: Average Life Expectancy (Core Indicator).

According to the ISO 37120, "life expectancy reflects the overall mortality level of a population. Life expectancy is closely connected with health conditions, which are an integral part of development. Mortality is also one of the variables that determine the size of human populations and their potential for future growth. Life expectancy at birth is also a measure of overall quality of life in a country and summarizes mortality at all ages. It can also be thought of as indicating the potential return on investment in human capital and necessary for the calculation of various actuarial measures." This indicator is defined in ISO 37120 as follows:

> "The average life expectancy shall be calculated as the average number of years to be lived by a group of people born in the same year, if health and living conditions at the time of their birth remained the same throughout their lives".

Indicator Competency Questions

1. (Factual) How many people were born in (cohort) year X.
2. (Factual) How many people for the (cohort) year X died in Year Y?

3. (Factual) What is the reported 'Average Life Expectancy' for city Z?
4. (Factual) What city has the highest/lowest Average Life Expectancy?
5. (Factual) In what year was cohort X born?
6. (Deduced) What is the Average Life Expectancy for a person born in year X?
7. (Factual) What are the living conditions for Cohort year X?
8. (Factual) Have the living conditions remained the same for Cohort year X in Year Y and Year Y+1?

2.2. ISO 37120 12.2: Number of in-patient hospital beds per 100,000 Population (Core Indicator)

This indicator is defined in ISO 37120 as:

> "The number of in-patient hospital beds per 100,000 shall be calculated as the total number of in-patient public and private hospital beds (Numerator) divided by one 100,000th of the city's total population (Denominator). The result shall be expressed as the number of in-patient public and private hospital beds per 100,000 of the city population.
>
> Hospital beds shall include in-patient and maternity beds. This shall include beds in wards, which are closed for reasons such as lack of health staff, and building works. It shall also include beds for patients admitted who require continual assistance (acute care), incubators and specialized care. It may not include day care beds, pre-anesthesia beds, wake-up beds, beds for members of a patient's family and beds for hospital staff".

Indicator Specific Competency Questions

1. (Factual) What city is the indicator for?
2. (Factual) For what year is the indicator value being measured?
3. (Factual) What type of bed is hospital bed X?
4. (Factual) How many inpatient hospital beds does a hospital X have?
5. (Factual) How many outpatient beds does hospital X have?
6. (Factual) Is hospital X public or private?
7. (Deduced) What public hospitals were included in the indicator?

2.3. ISO 37120 12.3: Number of physicians per 100,000 Population (Core Indicator)

The availability of physicians is an important indicator of the strength of a city's health system. There is evidence that the number of physicians is positively associated with immunization coverage, outreach of primary care, and infant, child and maternal survival (WHO, 2006). The following is the ISO 37120 definition (in this standard, physicians may also be referred to as doctors):

> "The number of physicians per 100,000 population shall be calculated as the number of general or specialized practitioners whose work-place is in the city (numerator) divided by one 100,000th of the city's total population (denominator). The result shall be expressed as the number of physicians per 100,000 population.

For this indicator, a physician shall be defined as someone who graduates from any accredited facility or school of medicine whose workplace is in the city.

FTE status shall be applied, in order to capture doctors working part-time in hospitals and in practices.

Data Sources:

Cities should report the number of physicians based on administrative records such as registered physicians in the City. Information may also be obtained from the census, labour force statistics and other surveys, which inquire about occupation."

Indicator Specific Competency Questions

1. (Factual) What educational institution did Physician X graduate from?
2. (Deduced) Is the educational institution accredited?
3. (Factual) Does a Physician X have a license?
4. (Factual) What educational qualifications does Physician X have?
5. (Factual) How many Physicians are general practitioners?
6. (Factual) How many Physicians are specialized practitioners?
7. (Consistency Internal) How many hours does a full time physician work?
8. (Factual) What specializations exist in city X?

2.4. ISO 37120 12.4: Under age five mortality per 1,000 live births (Core indicator)

According to the ISO 37120 standard, "The under age five mortality rate is a leading indicator of the level of child health and overall development in cities. Child mortality is an indicator of the status of the city as a healthy or an unhealthy place to live in. In addition, mortality rates are among the most frequently used indicators to compare levels of socioeconomic development across countries. Improving child mortality rates is a vital component of the Millennium Development goals." ISO 37120 defines this indicator as:

"The under age five mortality per 1,000 live births shall refer to the probability of a child born in a specified year, dying before reaching the age of five, and shall be expressed as a rate per 1,000 live births.

Age specific mortality rates among children and infants shall be calculated from birth and death data derived from vital registration, census, and/or household surveys. Estimates based on household surveys data shall be obtained:

a) directly, using birth history, as in demographic and health surveys, or
b) indirectly, using the Brass method, as specified in the Multiple Indicator Cluster Surveys.

The data shall then be summed for children under age five and shall be expressed as a rate per 1,000."

Indicator Specific Competency Questions:

1. (Factual) How many infants were born in (Cohort) year X?
2. (Factual) How many infants of (Cohort year X) die in year Y?
3. (Factual) What (cohort) is (infant X) a member of?

4. (Factual) What did (infant) X die of?
5. (Deduced) How many infants born in Year X are still alive after 5 years?
6. (Factual) What is the source of birth data for year X?
7. (Factual) What is the source of the death data for year X?
8. (Deduced) Was the birth/death data directly/indirectly derived?

2.5. ISO 37120 12.5: Number of nursing and midwifery personnel per 100,000 population (Supporting Indicator)

According to the ISO 37120 standard, this indicator "is a good indication of the city health system, and the strength of its outreach for maternal health."

> "The number of nursing and midwifery personnel shall be calculated as the total number of nurses and midwives (numerator), divided by one 100,000th of the city's population (denominator). The result shall be expressed as the number of nursing and midwifery personnel per 100,000 population.
>
> The number of nurses shall include actively practicing nurses and midwives employed in public and private hospitals, clinics and other health facilities, including self-employed nurses and midwives. Both fully qualified nurses with post-secondary education in nursing and vocational/associate/auxiliary/practical nurses with a lower level of nursing skills but also usually registered, shall be reported."

Indicator Specific Competency Questions

1. (Factual) Is person X a nurse or a midwife?
2. (Factual) What type of nurse is person X?
3. (Factual) Is person X actively practicing?
4. (Factual) Does a nurse/midwife have a license?
5. (Factual) Was a nurse/midwifes' license issued by the state/provincial licensing body?
6. (Factual) From what educational institution has a nurse/midwife received her education?
7. (Deduced) Is the educational institution accredited?
8. (Factual) Is the nurse or midwife employed in the city?
9. (Factual) When did the nurse become certified?

2.6. ISO 37120 12.6: Number of mental health practitioners per 100,000 population (Supporting Indicator)

As described in the ISO37120, "Mental health is central to human development. Positive mental health is liked to a range of development outcomes, including better health status, higher educational achievement, enhanced productivity and earnings, improved personal relationships, better parenting, closer social connections and improved quality of life. Positive mental health is also fundamental to coping with adversity." The definition of this indicator is:

> **"**The number of mental health practitioners per 100000 population shall be calculated as the total number of mental health practitioners whose work place is in the city (numerator) divided by one 100,000th of the city's total population (denominator). The result shall be expressed as the number of mental health practitioners per 100,000 population.

Mental health practitioners shall refer to psychiatrists, clinical psychologists, clinical social workers, psychiatric nurses and mental health counsellors."

Indicator Specific Competency Questions

1. (Factual) What type of mental health practitioner is a Professional Healthcare Provider X?
2. (Factual) How many psychiatrists, clinical psychologists, clinical social workers, psychiatric nurses and mental health counsellors are working in a Healthcare Facility X?
3. (Factual) What city does a Mental Health Practitioner Y work in?

2.7. ISO 37120 12.7: Suicide rate per 100,000 population (Supporting Indicator)

According to the ISO 37120, "Suicide rate is a serious issue in many cities and reflects on mental health in a city which is central to human development." The indicator is defined as:

> **"**The number of deaths by suicide per 100,000 population shall be calculated as the total number of reported deaths by suicide (numerator) divided by one 100,000th of the city's total population (denominator). The result shall be expressed as the number of deaths by suicide per 100,000 population.
>
> Deaths by suicide shall refer to acts deliberately initiated and performed by a person who fully acknowledges the fatal outcome of such acts.
>
> **Data Sources**
>
> This information should be obtained from the coroner's office, regional health authority or national census."

Indicator Specific Competency Questions

1. (CI) Is the death of Resident X a suicide?
2. (CI) Who determines (whether) a death is a suicide (Coroner's office)?
3. (CI) Was the determination of suicide official?
4. (F) How many deaths within a city are suicides?
5. (F) What are the causes of deaths reported in a city?
6. (F) What is the source of the suicide data?

3. Background

Our focus is the development of a healthcare ontology that will enable the representation of the definition of each healthcare indicator and answer their corresponding competency questions. We build on the Global

City Indicator Foundation ontology (Fox, 2013)[1]. That work integrates and extends existing ontologies depicted in Figure 1. The ontologies included are:

- Time (Hobbs & Pan, 2006).
- Measurement (Rijgersberg et al., 2011).
- Provenance (Lebo et al., 2013).
- Statistics (Pattuelli, 2009).
- Validity (Fox & Huang, 2005).
- Trust (Huang & Fox, 2006).
- Placenames (www.geonames.org).

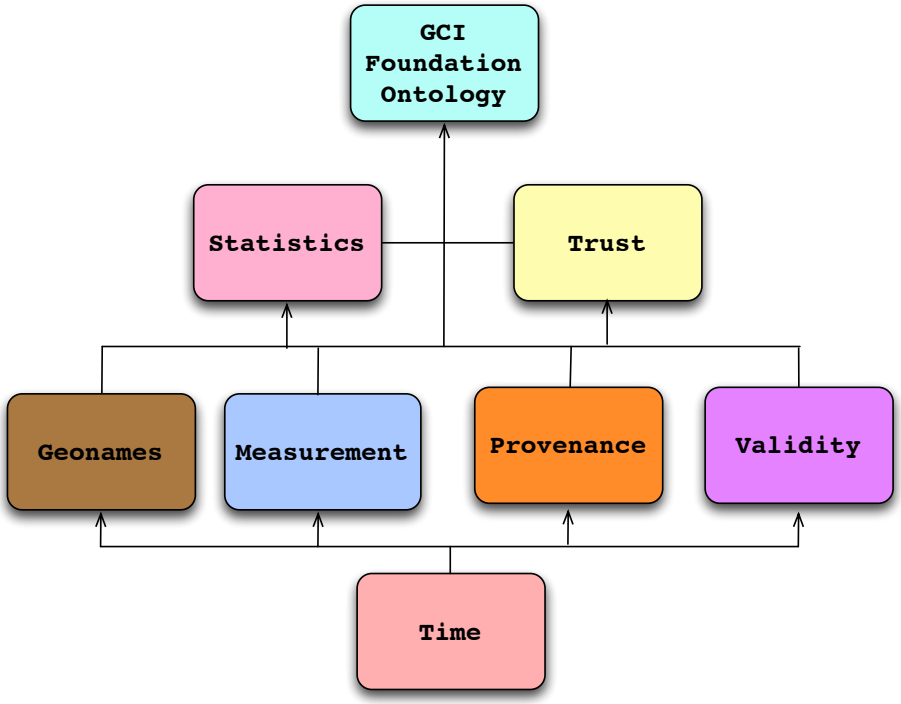

Figure 1: GCI Foundation Ontology Components

To be able to provide answers to our competency questions, we have to extend the Global City Indicator Foundation ontology. Specifically, we will require definitions for:

1. The concept of a hospital; with a distinction between public and private.
2. The concept of a license (Licensure); medical professionals require licensure as pre-conditions to work. This applies to several indicators.
3. The definition of mental health professionals and associated subclasses.
4. Educational Institutions and their accreditations; professionals must gain accreditation to satisfy the requirements for several indicators
5. The concept of educational qualifications

[1] The GCI Foundation ontology can be found at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.html. We will use the prefix "gci" where needed.

3.1. Alternative City Health Indicators

A number of organizations currently collect city data on healthcare indicators. These include the World Health Organization (W.H.O), The World Bank and The Kaiser Family Foundation (KFF). The KFF for example, gathers data on categories ranging from Income and Economy to the incidence of Tuberculosis around the world. Despite the data being collected, searches for current ontologies have shown that there is no exhaustive ontology that also provides a definition of classes, competency questions and axioms for the city health indicators we are looking at. After reviewing a wealth of potential projects in the same domain, we focused on assessing three alternative projects to determine the availability of well-defined indicators with supporting ontologies.

First, the World Health Organization (WHO) currently operates the Healthy Cities project[2]. According to their website, "the project engages local governments in health development through a process of political commitment, institutional change, capacity building, partnership based planning and innovative projects".

The project developed a set of 53 healthy city indicators to describe the health of its citizens and capture a range of local initiatives addressing wider dimensions of health in specific cities.

In a lessons learned report from the WHO, a major challenge to working with the indicators was whether comparative analysis is appropriate and valid. A major objective of the project was to be able to perform trend analysis over time and due to variability in the indicators, a comparison was only possible for 9 out of 53 indicators. In summary, the barriers to comparability stemmed from inconsistencies in:

1. Definition/interpretation.
2. Frequency of data collection.
3. Population being measured (part of the city, suburbs or other).

The report also found that the data is disparate, structured differently with no consistent definitions of what concepts in the indicators really mean.

Second, the City of Toronto maintains health surveillance indicators, "to help meet Ontario Public Health standards"[3]. The indicator set only has a few indicators common to the GCI Indicators, including "Life Expectancy" and "Infant Mortality". The indicator set did not include an accompanying ontology.

The third project examined is the European System of Urban Health Indicators (EURO-URHIS) funded by the European Union. The project defined 39 indicators that could be tested across 60 participating urban areas, although no ontology has been published to accompany these indicators. The goal of the project is to "support policy-making, identify and prioritize urban health problems on the basis of evidence and enable the monitoring of the effects of actions taken to address them. By using a standardized methodology for data collection, processing and dissemination, transnational comparisons and time trend analysis will become feasible"[4].

[2] http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/activities/healthy-cities
[3] http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=d69e6032bcaa6410VgnVCM10000071d60f89RCRD
[4] http://ec.europa.eu/health/indicators/other_indicators/urban_health/index_en.htm

3.2. Existing Ontologies

Health Ontologies

The GCI Health ontology defines concepts that span the seven health theme indicators. To represent the ontology, we will need to model concepts such as "healthcare providers", "hospitals and healthcare organizations", "licensure" and more. As part of the ontology engineering process, we identify, select and reuse portions of existing ontologies.

1. **SNOMED**[5] is a comprehensive, multilingual clinical healthcare vocabulary. It enables the consistent representation of clinical content in electronic health records. It is currently mapped to other international standards.

   SNOMED has definitions for healthcare providers, physicians, nurses as well as midwives. It also includes definitions for hospital, hospital bed. The healthcare worker class for example, is a subclass of the 'Occupation' class. Some subclasses of the healthcare worker class include 'Pharmacist', 'Medical Practitioner', 'Dentist' and a large number of other classes. Although, for concepts such as mental health practitioner for Indicator 12.6, there is no clearly defined class that we can map to. However, there is a class definition for 'Mental Health Nurse'.

2. Schema.org[6] on the other hand, contains the following relevant classes including Physician' and 'Dentist'. These classes are subclasses of 'MedicalOrganization' which does not map directly to 'Healthcare Provider'. 'Physician' has properties such as 'availableService' with a range of 'MedicalProcedure', 'MedicalTest' and similar concepts.

3. In addition to Schema.org, the obofoundry.org repository is focused on "developing a family of interoperable ontologies that are both logically well-formed and scientifically accurate". Within the foundry, we located a number of ontologies within the repository with classes of interest. The 'Ontology of Medically Related Social Entities' includes the 'Physician Role' class, a subclass of the 'health care provider role' class.

4. The Surveillance Lab at McGill University[7] defines a number of classes and indicators; however, these indicators are not global city indicators but are directed more at population health. The focus of the highly structured architecture developed at the lab **is to enable the creation of a** Health Indicators Ontology for health status indicators, for diseases and conditions. The Ontology however, is not focused on geographic level healthcare indicators. No relevant classes were found as a part of this ontology/work.

5. In addition to the above ontologies, an ontology for Tele-Health was located. The Tele-health Ontology (TEON) represents formal ontological content concerning the delivery of Telehealth services. The ontology reuses content from the Ontology of Biomedical Investigations (OBI). The Ontology was developed "for its applicability and potential to improve information exchange,

[5] www.snomed.com

[6] www.schema.org

[7] http://surveillance.mcgill.ca/km/Indicators/HealthIndicators.owl

interoperability and decision support" [8]. Some relevant classes within the ontology include 'Action', 'TelehealthService', 'TelemedicineService' and properties such as 'hasPatient'[8].

6. Another Ontology of interest is RxNorm[9]. RxNorm is a normalized naming system for medication and a tool that supports semantic interoperability between drug terminologies and pharmacy systems. It is maintained by the U.S. National Library of Medicine, containing normalized names for branded and generic clinical drugs. Concepts such as 'Medication' can be leveraged for the GCI Health Ontology.

7. The International Classification of Disease Ontology (ICD)[10] is the foundation for the identification of health trends and statistics globally, and the international standard for reporting diseases and health conditions. It is maintained by the WHO. The standard contains 12,445 classes for describing human disease states such as 'Malaria', 'Tuberculosis' and numerous infectious and parasitic diseases. It also accounts for specific term such as 'Intentional Self Harm' that can be leveraged a GCI Health indicator.

However, not all the ontologies listed above come packaged with the necessary definitions and axioms to enable reuse in our GCI Health ontology. The ontologies focus on representing the incidence and prevalence of human diseases and disorders and therefore do not provide basic descriptions of classes for concepts such as 'physician', "nurse" or "doctor". In addition, the ontologies located do not offer the prerequisite properties necessary to model all the ISO 37120 Health Indicators.

3.3. Architecture of the ISO 37120 Ontology

The following diagram (Figure 2) depicts the organization of files used to define the ISO 37120 ontology we are developing. At the highest level, i.e., ISO 37120 Ontology level, the ISO 37120 module[11] contains the globally unique identifier (IRI) for each ISO 37120 indicator. For example, the IRI for the Student/Teacher Ratio indicator is: "http://ontology.eil.utoronto.ca/ISO37120.owl#6.5".

For each category of indicators in the ISO 37120 specification, for example Education, there is a separate file that provides the definition of each indicator in that category. For example, ISO37120/Education.owl[12] provides a complete OWL definition for all seven of the indicators in the ISO 37120 specification.

The GCI Ontology level provides the category specific ontologies required to define each category's indicators. For example, to define the ISO 37120 Education indicators, we need an educational ontology covering concepts such as schools, teachers, students, cohorts, etc. GCI-Education.owl[13] provides the classes used by ISO37120/Education.owl.

[8] http://journals.ukzn.ac.za/index.php/JISfTeH/article/view/143/518

[9] http://jbiomedsem.biomedcentral.com/articles/10.1186/2041-1480-4-44

[10] International Statistical Classification of Diseases and Related Health Problems (ICD-10). 10th rev. Geneva

[11] http://ontology.eil.utoronto.ca/GCI/37120.owl

[12] http://ontology.eil.utoronto.ca/GCI/ISO37120/Education.owl.

[13] The GCI Education ontology can be found at http://ontology.eil.utoronto.ca/GCI/Education/GCI-Education.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Education/index.html. We will use the prefix "gcie" where needed.

All of the category specific indicator ontologies rely about the GCI Foundation ontology[14] for more generic concepts such as population counts and ratios, meta-information, etc.

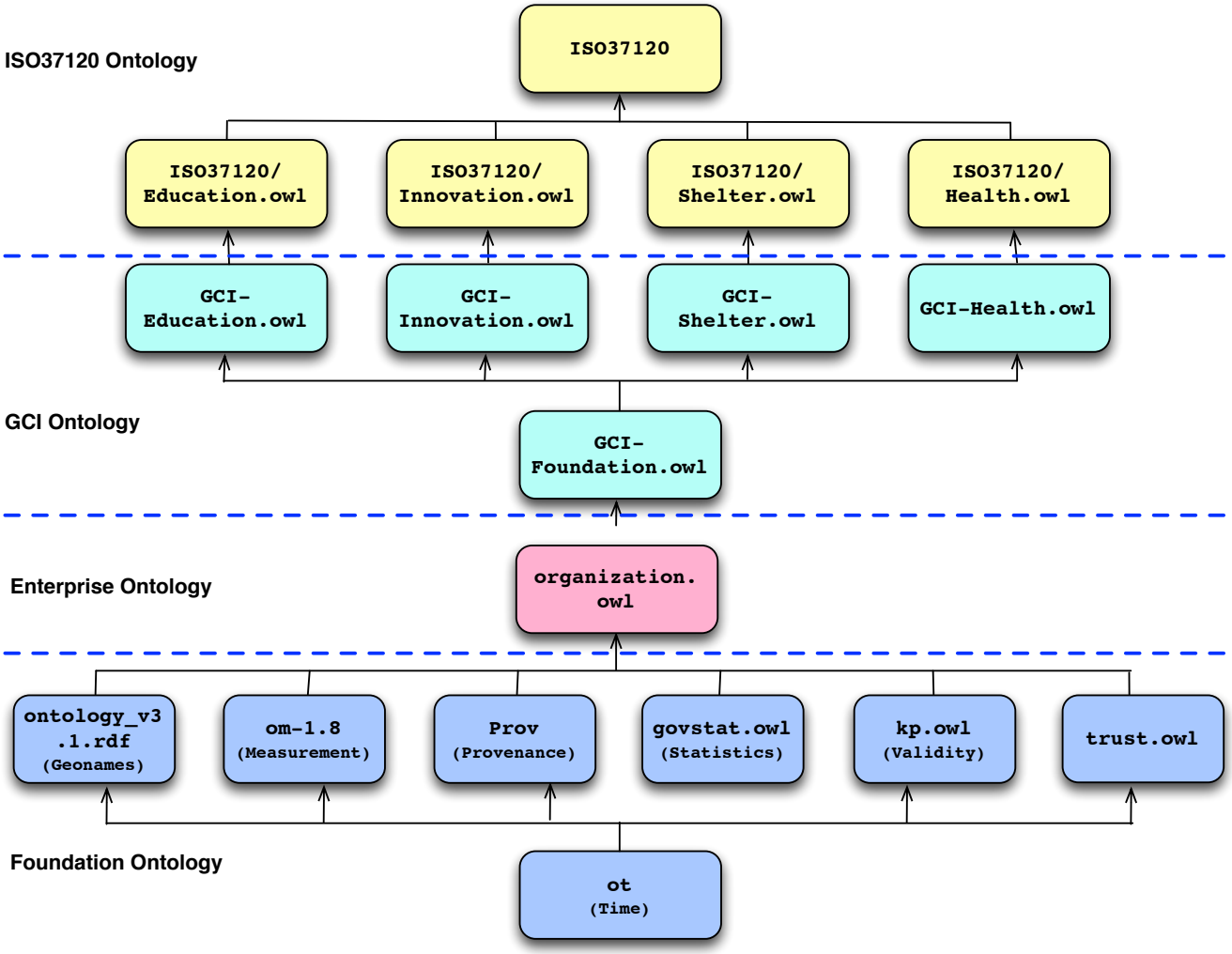

Figure 2: ISO 37120 Ontology Modules

The Enterprise Ontology level contains Enterprise Modelling ontologies. In this figure, we only show the Organization Ontology file[15] (Fox et al., 1998), which is one of the TOVE Enterprise Modelling ontologies (Fox & Grüninger, 1998). In addition to the Organization ontology, TOVE has ontologies spanning:

- Activities and States (Gruninger & Fox, 1994)
- Resources (Fadel et al., 1994; Fadel, 1994).
- Quality Measurement (Kim & Fox, 1994).

[14] The GCI Foundation ontology can be found at http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl along with its documentation at http://ontology.eil.utoronto.ca/GCI/Foundation/index.html. We will use the prefix "gci" where needed.

[15] The Organization ontology can be found at http://ontology.eil.utoronto.ca/organization.owl along with its documentation at http://ontology.eil.utoronto.ca/organization.html. We will use the prefix "org" where needed.

- Activity-Based Costing (Tham et al., 1994).
- Product (Lin et al., 1997).
- Product Requirements (Lin et al., 1996).
- Human Resources (Fazel-Zarandi & Fox, 2012).

Finally, the Foundation Ontology level provides very basic ontologies that were selected as the foundation for the GCI-Foundation.owl ontology described in section 0.

4. GCI Healthcare Micro-Ontologies

In order to represent the definitions of the ISO 37120 indicators and be able to answer the competency questions outlined earlier, it is necessary to define concepts that are otherwise not included in the GCI Foundation Ontology.

4.1. Licensure Micro-Ontology

As is evident in the descriptions of the competency questions for indicators 12.5, 12.5 and 12.6, a physician, nurse of midwife requires a License, by law to deliver care. We will define a Licensure taxonomy to support the assertion that healthcare professionals require a license to practice. This taxonomy will apply to several indicators within the GCI Health ontology including 12.3 (Number of Physicians per 100,000), 12.5 (Number of Nursing/Midwifery Personnel per 100,000) and 12.6 (Number of Mental Health Practitioners per 100,000).

Competency Questions

1. Who is the issuing agency for a license?
2. Who is the license holder?
3. Is the license valid for the current year?

We have also attempted to locate a license ontology available for reuse. According to an existing taxonomy (The Biomedical Resource Taxonomy)[16], a license is a resource that provides access to documented permission to do something, either from government or under a law or regulation. This concept is not part of an ontology with fully defined specifications.

In a different domain, the AgriVivo taxonomy offers a definition for a license[17]. A License is described as a subclass of a "IssuedCredential", with properties like license number. According to the concept definition here, "the legal authority or formal permission from authorities to carry on certain activities which by law or regulation require such permission. It may be applied to licensure of institutions as well as individuals[18].

In yet another domain, OpenCYC defines the concept of a "License Holder" with the following definition: "A license has been issued to agent by the appropriate authority". Here, each instance of the "License IBO" class

[16] http://bioportal.bioontology.org/ontologies/BRO?p=classes&conceptid=http%3A%2F%2Fbioontology.org%2Fontologies%2FBiomedicalResourceOntology.owl%23License

[17] http://www.agrivivo.net/ontology/vivo

[18] http://bioportal.bioontology.org/ontologies/MESH?p=classes&conceptid=http%3A%2F%2Fpurl.bioontology.org%2Fontology%2FMESH%2FD008004, Accessed February 26, 2014).

is a document recording some "License_LegalAgreement". For example, a "Healthcare Association" enters into a legal agreement with the "License Holder" with a "Physician_LicenseAgreement" or a "Midwifery_LicenseAgreement".

We illustrate the License class as defined by the Biomedical Resource Ontology[19] below:

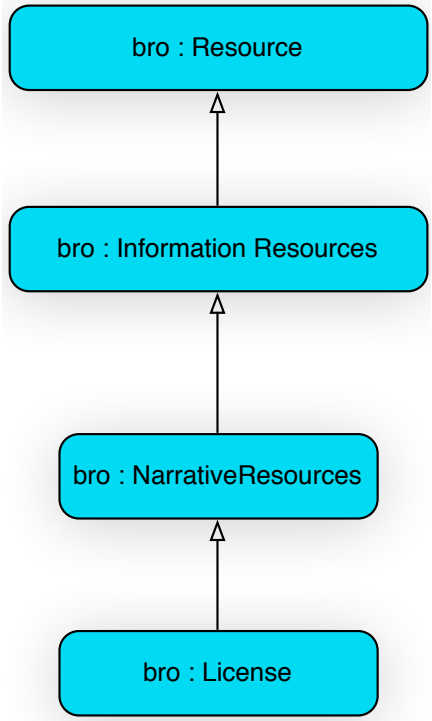

Figure 3: Licensure Class

Class	Property	Value Restriction
License	Issued_By	HealthcareAssociation
	isValidFor	time:DateTimeInterval
	licenseType	LicenseType
	Issued_To	Exactly 1 LicenseHolder
LicenseHolder	holds	min 1 License

A License will have many types and can be issued to different healthcare professionals. For example, there will be Physician License Agreements, Nursing Licensing and more. As such, we will be defining the requirements for a License at large.

[19] http://bioportal.bioontology.org/ontologies/BRO/?p=classes&conceptid=http%3A%2F%2Fbioontology.org%2Fontologies%2FBiomedicalResourceOntology.owl%23License

4.2. Residency Ontology

As defined in the GCI Foundation Ontology (Fox, 2017) and the GCI Innovation Ontology (Forde, Fox, 2015), a resident denominator pattern has been defined for the population of city residents. The idea is that only true residents of a city are included in the data reported by cities. According to that paper, "City_Population_Size" is the common denominator which we will apply to indicators 12.2, 12.3, 12.6 and 12.7 respectively. An illustration of the pattern is shown below:

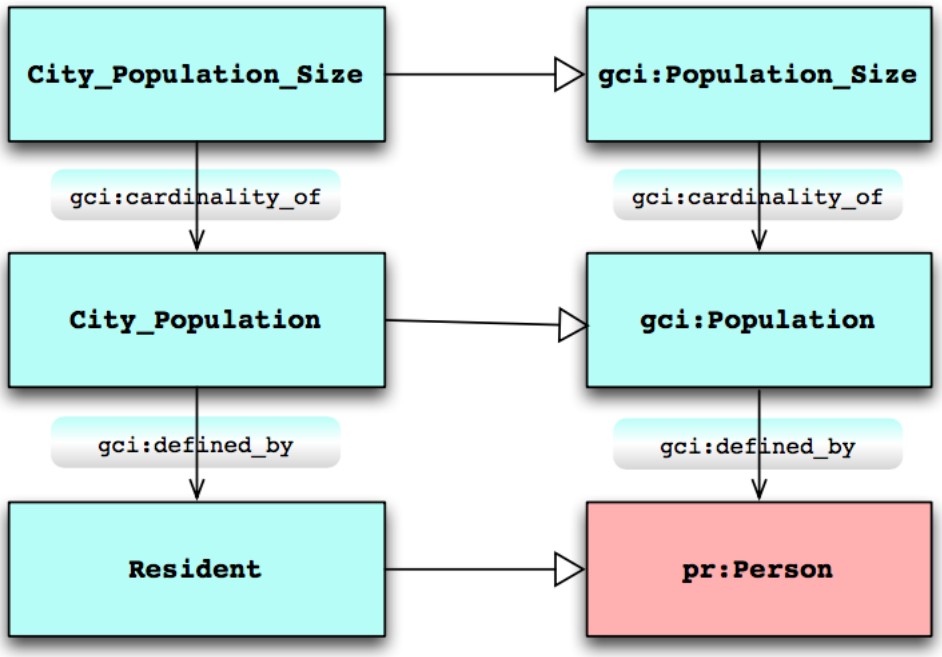

Figure 4: Resident Population Denominator Pattern

4.3. Healthcare Professional Ontology

A quick review of the competency questions described in Section 2.1 to 2.7 illustrates the need for additional concepts that speak to the different types of healthcare professionals including 'Physician', 'Nurse or Midwife', 'Mental Health Professional'.

The following competency questions highlight Healthcare Professional concept requirements.

1. What educational institution has a physician graduated from? (Factual)
2. Is the educational institution accredited? (Deduced)
3. What educational qualifications does the physician have? (Factual)

4. How many physicians are general practitioners? (Factual)
5. How many physicians are specialized practitioners? (Factual)
6. What is a FTE physician? Is there a minimum number of hours to be worked to be considered 'full-time' or 'part-time'? (Factual)

The Systemized Nomenclature of Medicine (SNOMED) ontology describes a physician but does not provide a definition. Similarly, the "Psychology Ontology" provides a taxonomy for healthcare professionals but no clear axioms.

The National Cancer Institute Thesaurus[20], one of the common taxonomies in the healthcare space, defines a nurse as "A professional healthcare provider who has graduated from an accredited nursing program, has passed the state exam for licensure, and been registered or licensed to practice by a state authority. Nurses are educationally prepared as functional (LPN/LVN) or professional (RN). The ontology is adapted from the Education Ontology (Fox, 2015[21]). The concepts of interest can be represented as shown below:

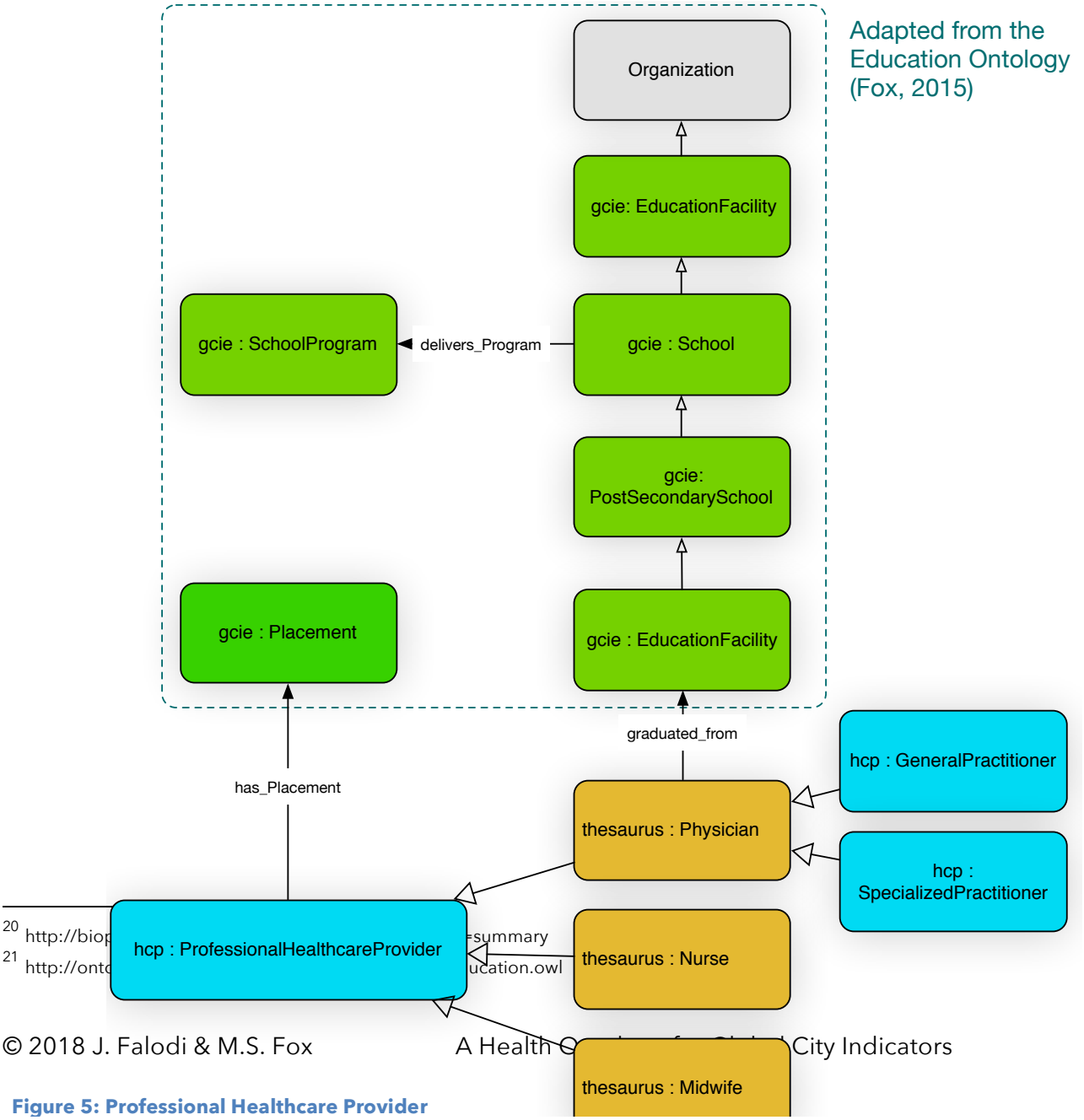

Figure 5: Professional Healthcare Provider

Class	Property	Value Restriction
ProfessionalHealthcareProvider	owl:subClassOf has_Placement	Org:OrganizationAgent >1 Placement
Physician	owl:subClassOf	hcp:ProfessionalHealthcareProvider
Nurse	owl:subClassOf	hcp:ProfessionalHealthcareProvider
Midwife	owl:subClassOf	hcp:ProfessionalHealthcareProvider

We will use the 'equivalentClass' property to link some of these concepts (healthcare professionals) to existing ontologies. For example, the concept of a 'physician' is also defined in other ontologies such as LOINC[22] and SNOMED[23,24].

To fulfil the employment requirements for healthcare workers in cities, we will ground that area in a "Placement" concept that speaks to where a care provider works. This is adapted from the paper by (Fox, 2015).

Class	Property	Value Restriction
Placement	healthcare_Staff_At	HealthcareFacility
	days_Worked	Exactly 1 positiveInteger
	for_Year	Exactly 1 dateTime

Comments

The term physician and doctor both refer to healthcare providers in a city and for the purposes of defining the micro-ontology, they are synonymous. Although in certain countries, it is possible for healthcare to be provided by traditional physicians who do not have medical training.

To provide context, the scale of resources invested in social protection, given a country's statutory commitments are typically measured through healthcare and old age pension. With respect to this indicator, a proxy indicator of health professional staff density is measured as the relative difference between specific

[22] http://bioportal.bioontology.org/ontologies/LOINC?p=classes&conceptid=http%3A%2F%2Fpurl.bioontology.org%2Fontology%2FSTY%2FT097

[23] http://bioportal.bioontology.org/ontologies/SNOMEDCT/?p=classes&conceptid=http%3A%2F%2Fpurl.bioontology.org%2Fontology%2FSNOMEDCT%2F158965000

[24] G. Héja, G. Surján, and P. Varga, "Ontological analysis of SNOMED CT.," *BMC Med. Inform. Decis. Mak.*, vol. 8 Suppl 1, p. S8, 2008.

country staff density levels and the benchmark of 23 physicians, nurses and midwives per 10,000 population recommended by WHO[25].

Definition of a Physician

A physician may refer to different professionals in different contexts. The common definition of a physician may refer to a professional who delivers care in a hospital or clinic. On the other hand, there may be physicians employed in companies or factories or other institutions, providing care to the employees there. According to the Oxford English Dictionary, a physician is defined as "a person qualified to practice medicine, especially one who specializes in diagnosis and medical treatment as distinct from surgery". An alternative definition for a physician is 'healer'.

Cities often do not define the licensure requirements for physicians and other healthcare providers. These requirements are often set out by the province, state or local government and apply to cities. We will start by providing an overview of what a physician is from the WHO perspective. We will then define who a physician is, according to the legal entities (medical associations) that maintain a registration of who is licensed to practice medicine in a particular city.

According to the World Health Organization, a physician is a professional who practices medicine, which is concerned with promoting, maintaining or restoring human health through the study, diagnosis, and treatment of disease, injury and other physician and mental impairments. They may focus their practice on certain disease categories., types of patients or methods of treatment - known as specialist medical practitioners - or assume responsibility for the provision of continuing and comprehensive medical care to individuals, families and communities - known as general practitioners.

In Ontario specifically, a physician is defined as a person licensed under Part III of the Health Disciplines Act under the Regulated Health Professions Act (1991). Further to this definition[26], In Ontario, family medicine physicians provide primary care[27], which includes the diagnosis and treatment of diseases, disorders and injuries, as well as health promotion and disease prevention.

Some Ontario family medicine doctors set up or join a practice - including an inter-professional team. Other family medicine doctors work in hospitals, clinics and community health centres. Family physicians may have a practice that encompasses different components such as office and hospital emergency room.

In British Columbia[28], "A family physician is an individual who has completed a two-year residency program specializing in family medicine. They are trained to treat the whole person. Rather than specializing in one type of care or one disease, they provide care for all parts of the body, all diseases, in all ages and genders".

In Australia, The Royal Australian College of Physicians defines a physician as 'often being called medical specialists'. Physicians in this case have completed an extra eight years or more of training after their initial

[25] http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_243961.pdf (Page 142)

[26] http://www.healthforceontario.ca/en/Home/Physicians/Training_%7C_Practising_in_Ontario/Physician_Roles

[27] http://www.healthforceontario.ca/ru/pdfs/RU_LicensingSupervision.pdf

[28] http://www.bcfamilyphysicians.com/faqs/

university medical training. Patients are generally referred to a physician or pediatrician by a general practitioner seeking expert medical advice.

According to the Delhi Medical Association[29], "Any person possessing medical qualifications as defined in the Indian Medical Degrees Act (1916) and duly registered under the Indian Medical Council Act" (will be eligible for membership).

In the US[30], all states and territories require doctors to pass the United States Medical Licensing Examination (USMLE) as a demonstration of basic competence to treat patients. Doctors must graduate from an accredited medical school to be eligible for the USMLE. However, this licensing does not establish competence to practice a specialty. The American Board of Medical Specialties (ABMS) and the American Osteopathic Association (AOA) oversee this certification. Physicians are also required to rectify periodically and the certifications are valid for a period of 10 years. They are also required to achieve a certain number of hours of continuing medical education credits over a 3-year period.

In some parts of rural Africa, in addition to the delivery of care by physicians, community health workers often deliver healthcare. Community health workers have a defined scope of practice that varies across countries. A community health worker receives one year of training, 3 months in a classroom and 9 months while in service, plus supervision and feedback[31]. They also receive a yearly refresher course lasting 20 hours. In Pakistan, there is a 'Lady Health Worker' program[32], which has requirements such as 8 years of schooling. Other requirements include a) local residency; b) possession of middle school pass; c) preferably married; d) minimum age of 18; and e) recommended by/acceptable to the community. The ladies take part in a 15-month training course, along with 12 months of practical on the job training.

In Nigeria, the medical and dental council of Nigeria maintains a 'registration of individuals entitled to practice medicine in that country' as medical or dental professionals. This also includes specialist medical practitioners.

In summary, there are multiple healthcare models around the world[33] with varying descriptors. For more on this, see the Role Ontology[34].

Definition of a Nurse and Midwife

The key to the grounding the definition of a nurse also revolves around Licensure. A regulatory body grants a license, certifying the nurse to have completed all the educational and training requirements necessary to hold that license[35].

In addition, the EU maintains brief definitions of regulated professions and what they mean[36].

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29 http://www.delhimedicalassociation.com/images/DMA.pdf

30 http://education-portal.com/doctor_certification.html

31 http://www.who.int/bulletin/volumes/91/4/12-109660/en/

32 http://www.who.int/workforcealliance/knowledge/case_studies/CS_Pakistan_web_en.pdf

33 http://www.jhsph.edu/research/centers-and-institutes/johns-hopkins-primary-care-policy-center/Publications_PDFs/A238.pdf)

34 http://bioportal.bioontology.org/ontologies/ROLEO

35 http://en.wikipedia.org/wiki/Nursing

The same regulating entity commonly licenses both nurses and midwives. In some countries, midwifery is considered as a level of nursing. In Japan for example, the levels correspond to practical nurses, registered nurses, midwives and then public health nurses[37]. The Japanese nursing association, under commission by the national government, issues licenses to nurses and renewals are not required. In the US, nurses are certified by the ANCC (The American Nurses Credentialing Centre). For example, until recently in Zambia, nurses and the midwives were governed by the same professional association, the Zambia Nurses Association.

In Canada, the College of Nurses of Ontario is the regulatory body for nursing practice in Ontario. The CNO regulates nursing to protect the public interest and sets requirements to enter the profession, establishes and enforces standards of nursing practice, and assures that the quality of practice of the profession and the continuing competence of nurses. To be recognized as a nurse, membership of the CNO is a prerequisite along with a valid certificate of registration.

Around the world, the International Confederation of Midwives regulates and sets standards for midwifery competence around the world[38]. These standards provide a professional framework that can be used by midwifery organizations, regulators and governments to strengthen the midwifery profession and raise the standard of midwifery practice in their jurisdiction.

According to the UNFPA, in many countries, midwifery is still not regarded as an autonomous profession and hence not supported by suitable legislation regulating the practice and protecting the public[39]. The standard suggests that in countries with no regulatory governance over midwives, the ICM global standards can be used to develop regulation and oversight.

The requirements for midwifery include:

1. They have an education that is consistent with the ICM global standard for midwifery education.
2. They demonstrate the 'ICM Essential Competencies for Basic Midwifery' (2010) practice.
3. They practice autonomously within their prescribed scope of practice.
4. They demonstrate continuing competence to practice.

In other situations, a midwife may be professionally trained or be an elder in the community.

Definition of a Mental Health Professional

According to the Canadian Mental Health Association[40], a psychiatrist is a medical doctor with a specialty in the diagnosis and treatment of mental illnesses.

36

http://ec.europa.eu/internal_market/qualifications/regprof/index.cfm?action=profession&id_profession=12402&tab=countries&quid=2&mode=asc&pagenum=3&maxrows=15#top

37 http://www.nursingworld.org/MainMenuCategories/ANAMarketplace/ANAPeriodicals/OJIN/TableofContents/Volume52000/No2May00/JapanElderlyCentury.html

38 http://www.internationalmidwives.org/assets/uploads/documents/Global%20Standards%20Comptencies%20Tools/English/GLOBAL%20STANDARDS%20FOR%20MIDWIFERY%20REGULATION%20ENG.pdf

39 http://www.unfpa.org/sites/default/files/resource-pdf/Midwifery%20Programme%20Guidance.pdf) pp24, pp 26

40 http://www.cmha.ca/mental_health/getting-help/#.VPOoS0LZqTA

Psychologists, on the other hand are trained to assess, diagnose and treat mental health problems and disorders. They hold a masters or doctoral degree in psychology and usually within a specific specialty or areas like clinical psychology or clinical neuropsychology[41].

"Other mental health professionals" assist patients with the recovery process and support their goals. These include nurses, social workers or occupational therapists.

In the U.S, the National Board for Certified Counsellors provides licensure for 'Mental Health Counsellors'. The is the National Counselor Examination for Licensure and Certification. Mental health counsellors are required to pass this examination to be able to practice.

According to the Canadian psychological association[42], to practice psychology is Canada, psychologists must be licensed. Licensure to practice is granted by regulatory bodies in each Canadian jurisdiction

While the structure of mental health services varies from one country to another, mental healthcare services especially public health systems generally consist of multi-disciplinary teams including psychotherapists, clinical and counselling psychologists, psychiatrists, counsellors and mental health social workers. Frontline mental healthcare workers are often complemented by family physicians and social workers[43].

4.4. Life Expectancy Classes

Within indicator 12.1 (Average Life Expectancy), we will utilize concepts from the foundation ontology to fully represent this indicator. The key concepts are the 'Sum' class and the 'Variable' class. The sum class will be used to capture the sum values of entities within a cohort.

[41] http://www.cmha.ca/mental_health/getting-help/#.VPOoS0LZqTA

[42] http://www.cpa.ca/practitioners/practiceregulation/

[43] D. Coyle and G. Doherty, "Towards ontologies for technology in mental health interventions," *Proc. - 1st Int. Work. Ontol. Interact. Syst. ONTORACT 2008*, pp. 18–26, 2008.

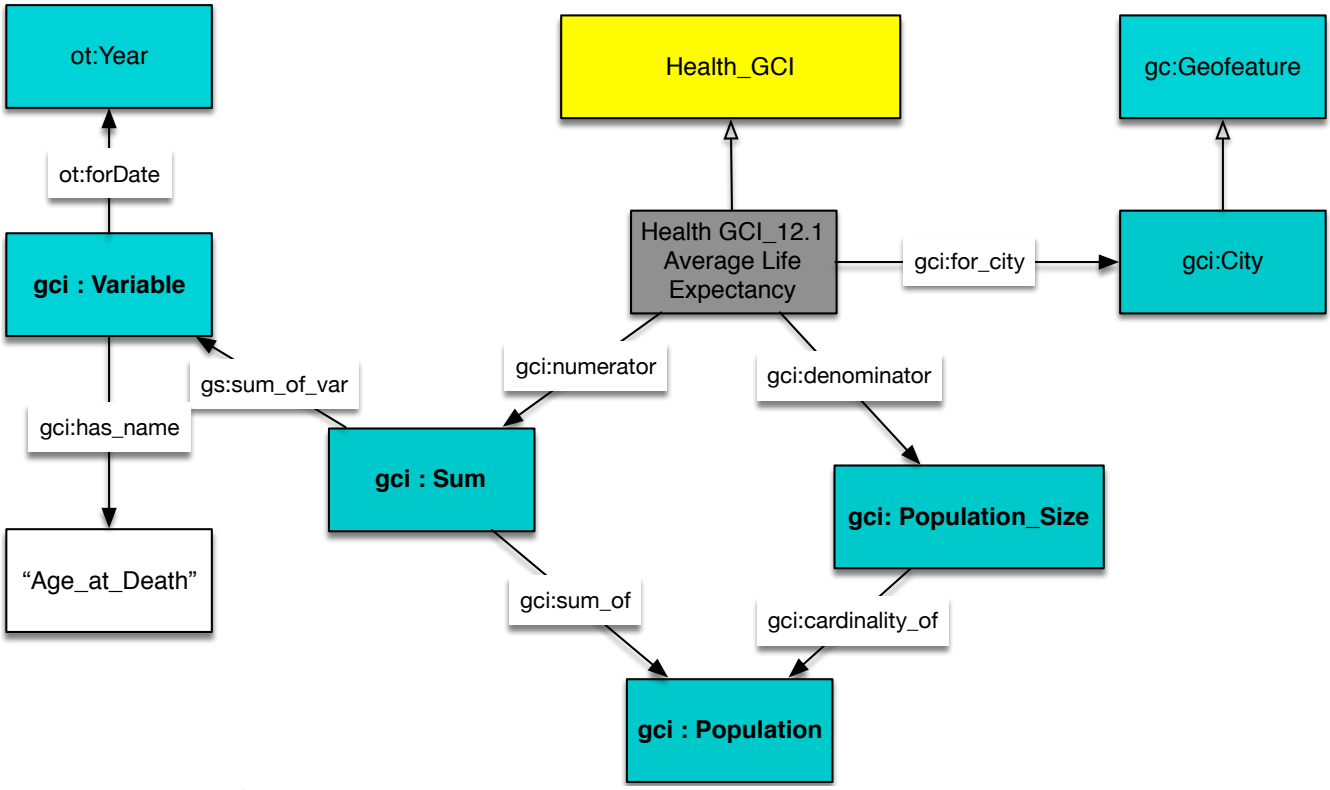


Figure 6: Average Life Expectancy Classes

4.5. Hospital Ontology

According to the Agency for Healthcare Research and Quality (AHRQ)[44], beds are grouped into licensed beds, physically available beds, staffed beds, unstaffed beds, occupied beds and vacant/available beds. The agency also further categorizes beds based on the type of patient that they serve.

Competency Questions

1. How many hospital beds does a hospital have?
2. Is a hospital bed situated within a private or public hospital?
3. What type of bed is a given hospital bed?
4. What is the minimum number of occupants for a hospital bed?

Current Ontologies

The schema.org ontology defines a hospital bed[45] as a subclass of 'Emergency Service', Civic Structure' and 'Medical Organization'. Similar to the other indicators, we did not locate axioms and class definitions for health indicators describing hospital beds in cities within pre-existing ontologies.

To measure the number of hospital beds in a city. The diagram below represents the public and private hospital bed classes:

[44] http://archive.ahrq.gov/research/havbed/definitions.htm

[45] http://bioportal.bioontology.org/ontologies/SCHEMA?p=classes&conceptid=http%3A%2F%2Fschema.org%2FHospital

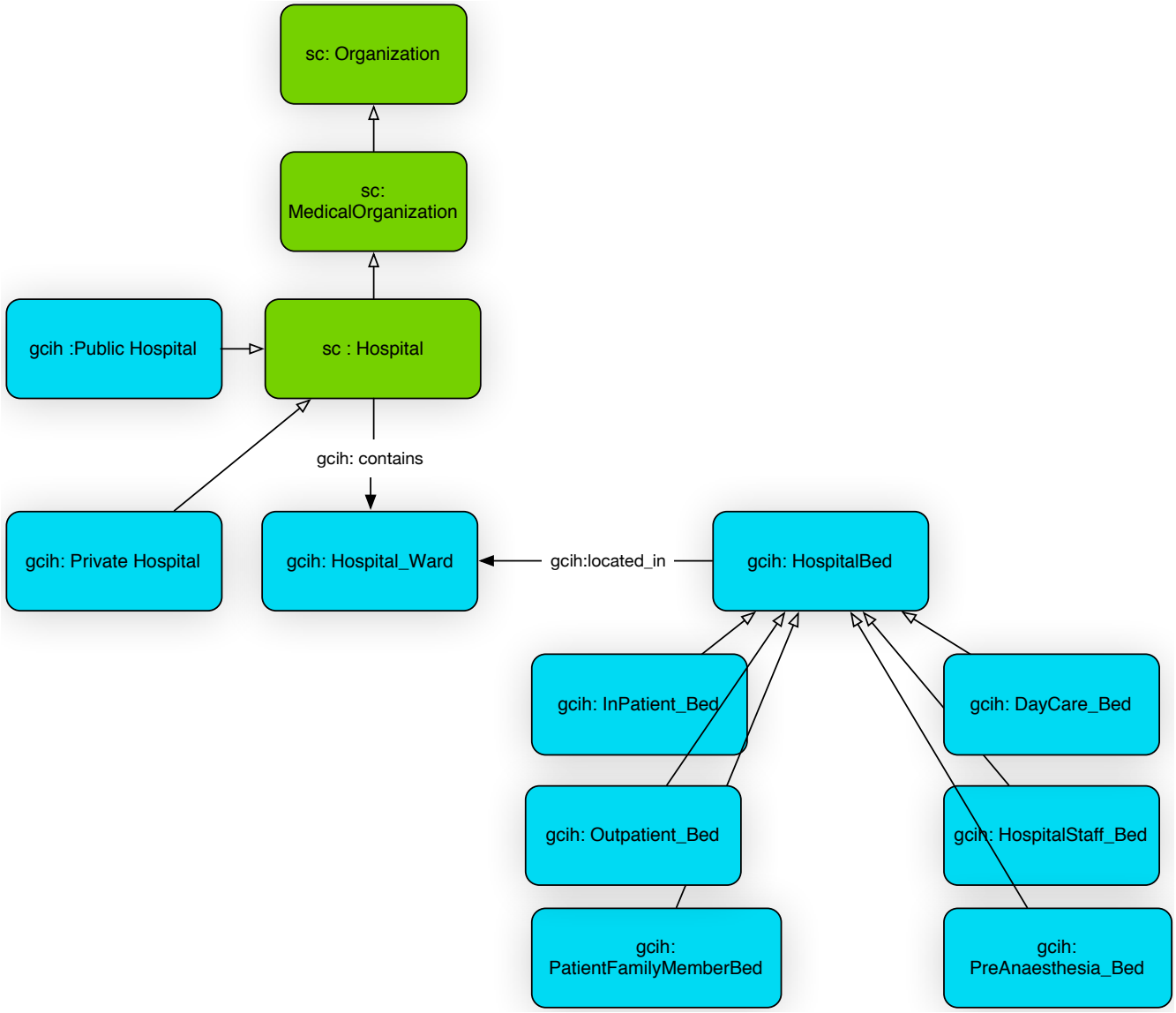


Figure 7: Hospital Classes

Class	Property	Value Restriction
Hospital	owl:subClassOf	sc:MedicalOrganization
	gcih:contains	gcih:Hospital_Ward
HospitalBed	gcih:located_in	gcih_Hospital_Ward
Outpatient_Bed	owl:subClassOf	gcih:Hospital_Bed
InPatient_Bed	owl:subClassOf	gcih:Hospital_Bed
PatientFamilyMemberBed	owl:subClassOf	gcih:Hospital_Bed

DayCare_Bed	owl:subClassOf	gcih:Hospital_Bed
HospitalStaff_Bed	owl:subClassOf	gcih:Hospital_Bed
PreAnaesthesia_Bed	owl:subClassOf	gcih:Hospital_Bed

4.6. Education Classes

As in the paper by the Fox, 2015, we will repurpose and extend the definition of an educational facility to answer some of the competency questions defined below. This will help us ground the requirements that a healthcare professional such as a physician, nurse/midwife or mental health professional must have graduated from an educational facility that provides the training requisite for that type of healthcare professional.

Competency Questions

1. Is a given post-secondary school a graduate school or a university?
2. Is a Graduate School certified?
3. What universities are included in the indicator?
4. What types of programs does a university offer?

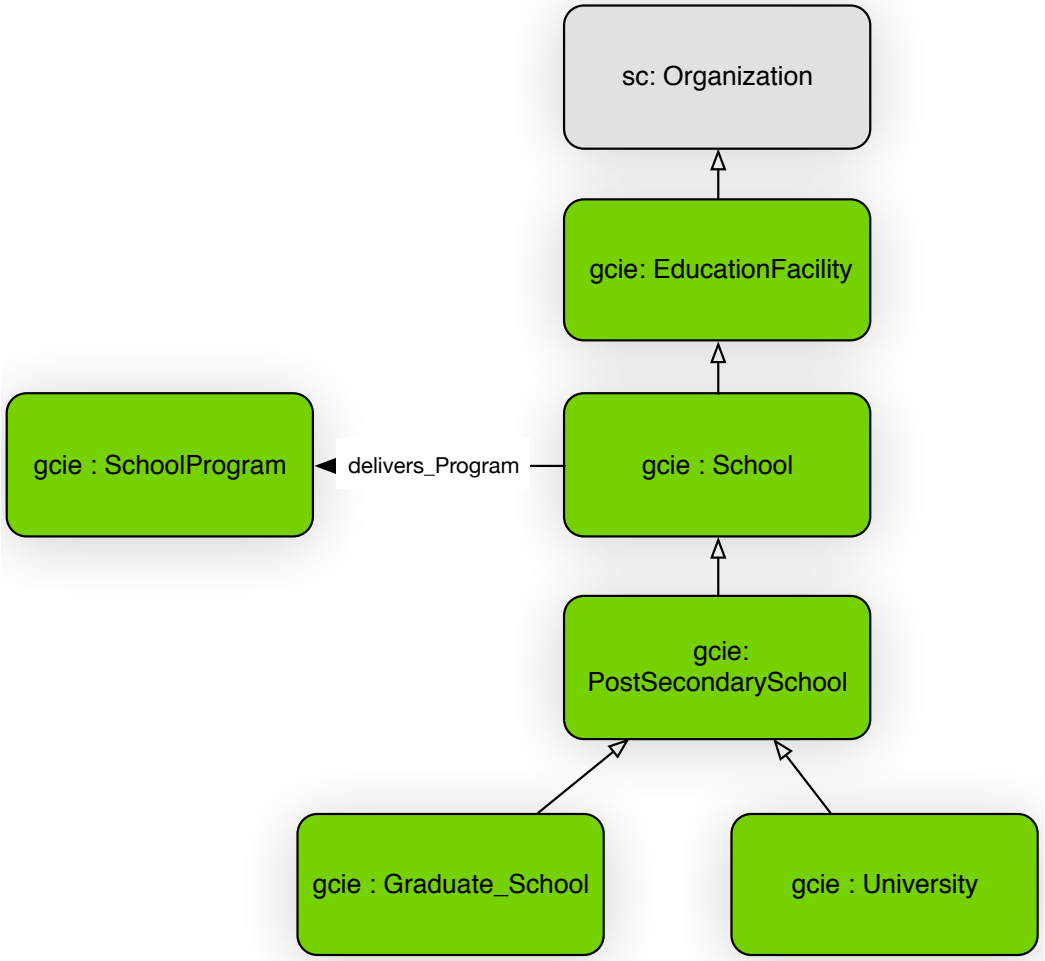


Figure 8: Education Classes 1 of 2

Class	Property	Value Restriction
gcie:School	owl:subClassOf	Some EducationFacility
	delivers_Program	some SchoolProgram
gcie:University	owl:subClassOf	gcie:School
	gcie:has_Certification	some gcie:Certification
gcie:Certification	gcie:certified_By	Some org:GovernmentOrganization
	gcie:certification_Date	exactly 1 ot:dateTime

We define educational institutions in terms of the education provided. For example, nursing degrees, medicine degrees, midwifery certifications and the like. It is not necessary that the educational institution be located within the same city.

The diagram below illustrates the classes used in this context. The "EducationalDegree" concept, extended from the Education Ontology as described in Fox, 2014:

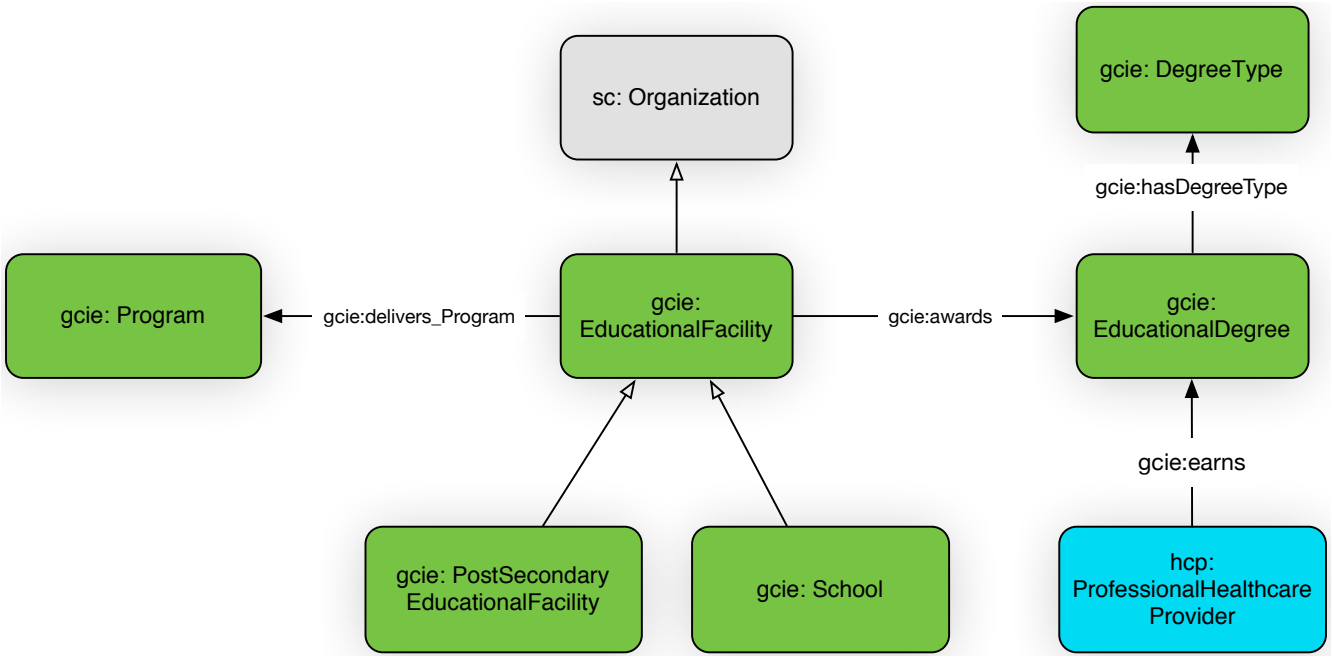
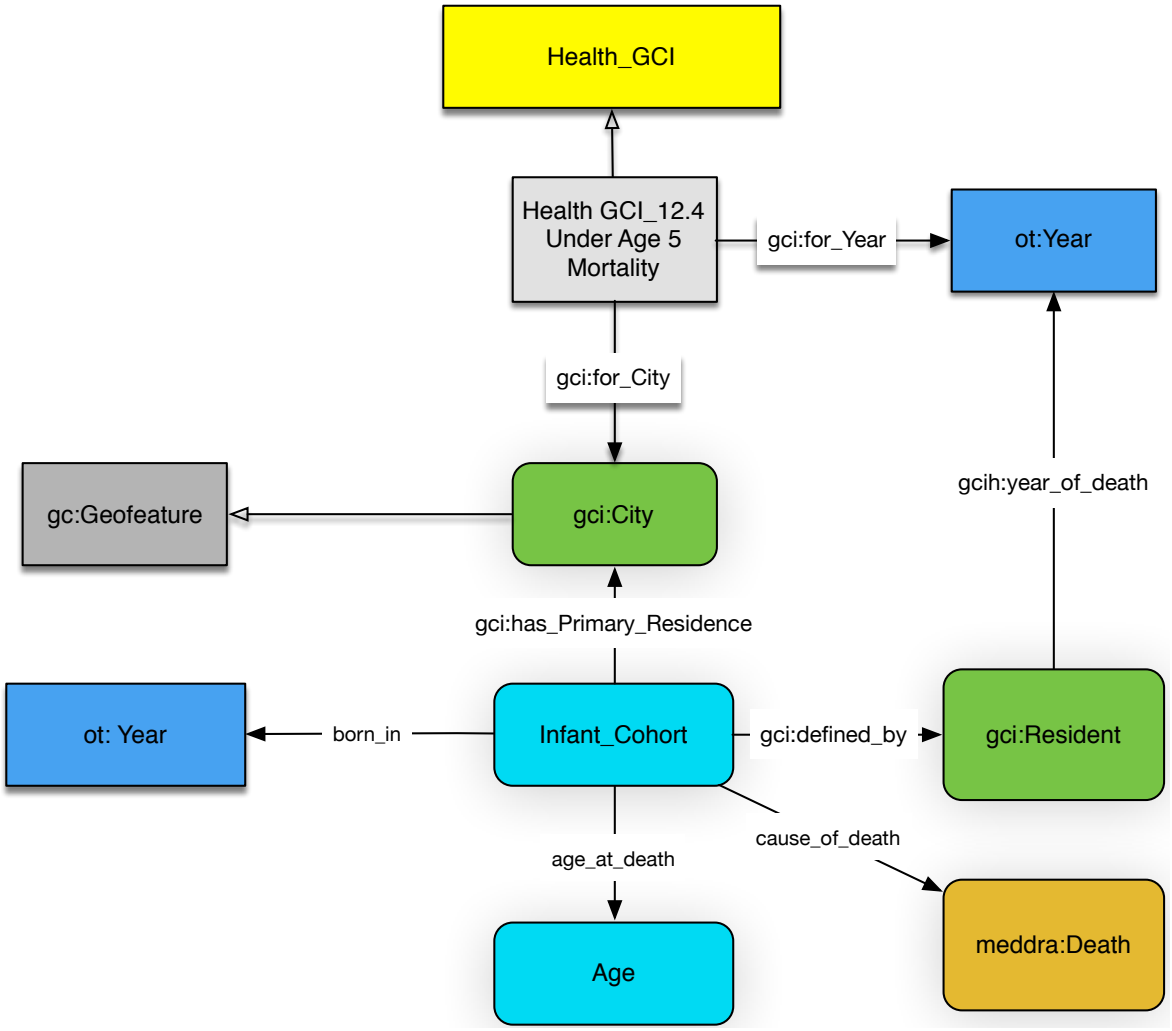


Figure 9: Education Classes 2 of 2

Class	Property	Value Restriction
gcie: EducationalFacility	owl:subClassOf	Organization
	delivers_Program	min 1 Program
	awards	min 1 EducationalDegree
PostSecondaryEducationalFacility	owl:subClassOf	EducationalFacility
School	owl:subClassOf	EducationalFacility
hcp:ProfessionalHealthcare Provider	gcie:earns	min 1 EducationDegree
gcie:EducationDegree	gcie:hasDegreeType	gcie:DegreeType

4.7. Mortality Class

The classes for the mortality ontology are extended from the Medical Dictionary for Regulatory Activities (MEDRA)[46]. The ontology includes definitions for 'fatal outcomes' (death) with the prefix 'meddra'.



4.8. Suicide Ontology Classes

In order to represent indicator 12.7 (Suicide Rate per 100,000). We will be defining classes for a 'Situation' (of which 'Suicide' is a subclass), which the assertion that the cause of the situation is 'Death'. Another assertion for a suicide is that it be committed by a 'Person' (or potentially a resident) and that it be reported by a valid/recognized Agency.

Competency Questions

[46] http://bioportal.bioontology.org/ontologies/MEDDRA?p=summary

1. Who committed a suicide event?
2. In which city did the suicide event occur?
3. Which city agency reported/recorded the suicide event?

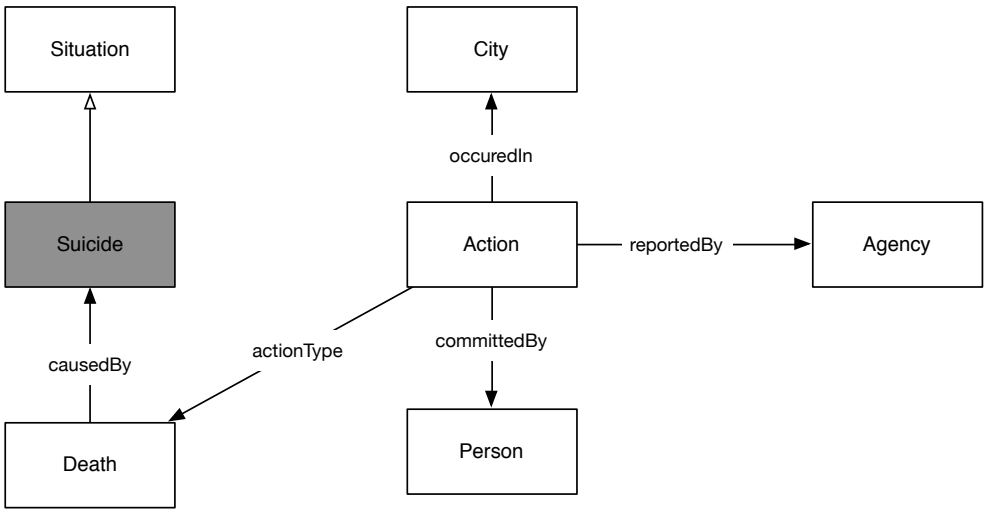


Figure 10

5. ISO 37120 Health Indicators Ontology

The GCI Health Ontology described at the beginning of this paper provides the classes and properties necessary to define all the indicators within ISO 37120 (12.1 to 12.7). (The ontology is defined in the following OWL file: http://ontology.eil.utoronto.ca/GCI/ISO37120/Health.owl.) In this section we define each Health indicator.

5.1. Average Life Expectancy (Indicator 12.1)

There are two approaches or options to calculating the Average Life Expectancy (ALE). First is a "Cohort Life Expectancy at Birth" which refers to the mean length of life of a cohort of individuals born in a particular year. What is commonly measured however, is the second option called "Period Life Expectancy at Birth"[47].

Our representation of this indicator will focus on the "Cohort Life Expectancy at Birth". The reason is that there has been limited information to define what is meant as "health and living conditions remaining the same throughout the life of a cohort". As such, we will use the mean length of life of a cohort of individuals born in a particular year. This is represented as an estimated value only. An alternative and simplistic calculation of the ALE is "an average of the age at death for a cohort". For example, for a group of individuals

[47] http://www.stats.govt.nz/browse_for_stats/health/life_expectancy/cohort-life-expectancy.aspx

born in 1911, the average life expectancy will be the average age of everyone in that cohort at their respective times of death.

This could be described as: $\frac{\sum_{(Ages\ at\ Death)}}{\#\ of\ Deaths}$

For the purpose of extensibility, we choose not to limit the definition of this indicator to a city but to a "geographical entity" as well. Looking at current data, reporting is commonly at the "Country" level as opposed to just the "City" level.

The indicator described above can be represented as follows:

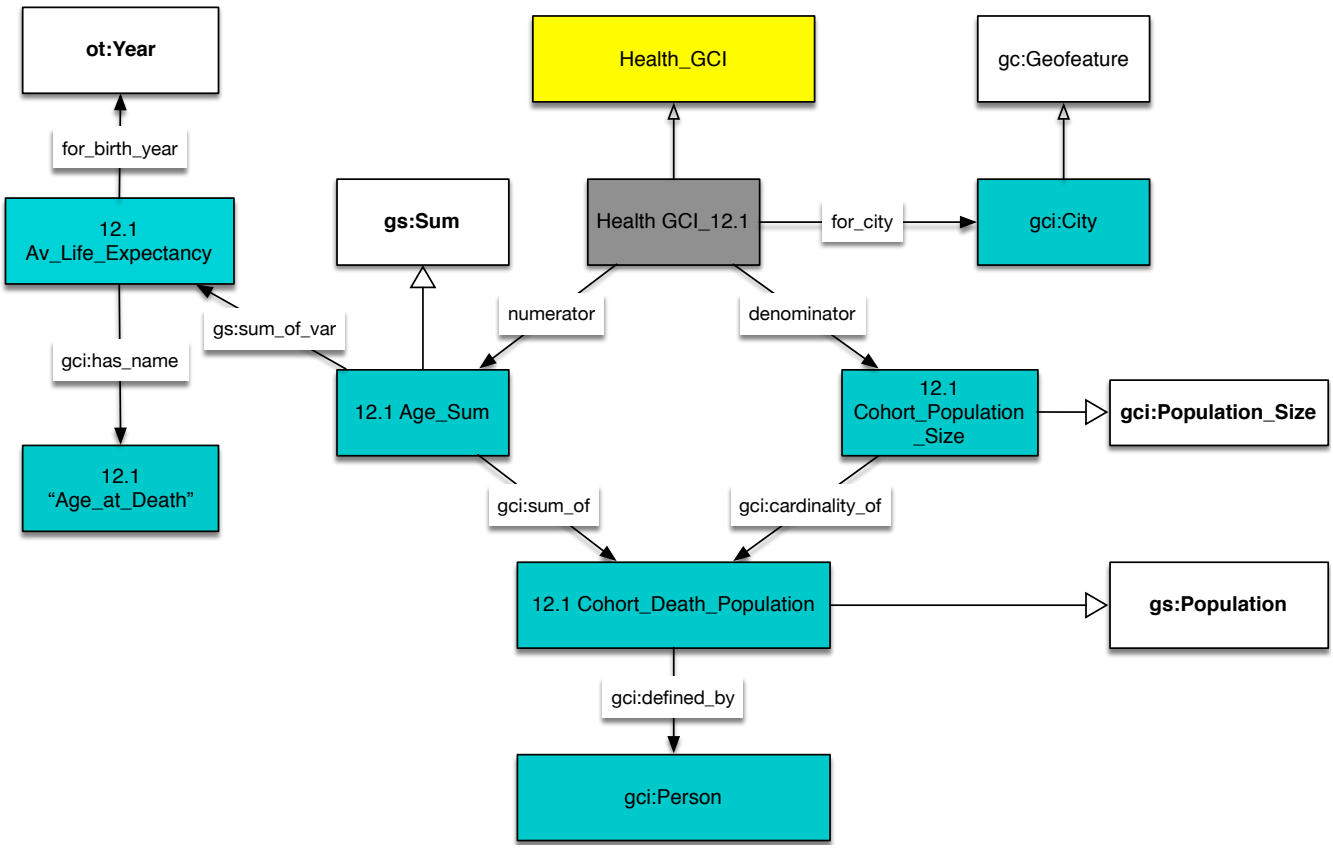


Figure 11: 12:1

This indicator is a ratio between the sum term quantity of ages of a population and a population size, as shown above. The numerator in this case refers to the sum of ages of members of the cohort at the time they died and the denominator refers to the population (cohort) of people born in year x who have died. The numerator can further be defined as a number and the denominator, a population count.

Class	Property	Value Restriction
gcih:Life_Expectancy_Value	gci_LE_unit	Om:Singular_Unit
	gci:for_city	gci:City
	gci_for_birth_year	ot:Year
	gci:is_an_estimate_of	gci: Statistic
City	owl:subClassOf	gc:SchemaOrgThing

5.2. Number of in-patient hospital beds per 100,000 (12.2)

The diagram below provides a brief description of how concepts could be represented for this indicator. We are trying to represent the set of hospital beds located in a hospital, also located in a placename (numerator) and the set of 100,000 residents of that placename (denominator). The size of each set can be identified by its cardinality[48].

[48] M. S. Fox, "Foundation Ontologies Requirements for Global City Indicators," pp. 9–15, 2014.

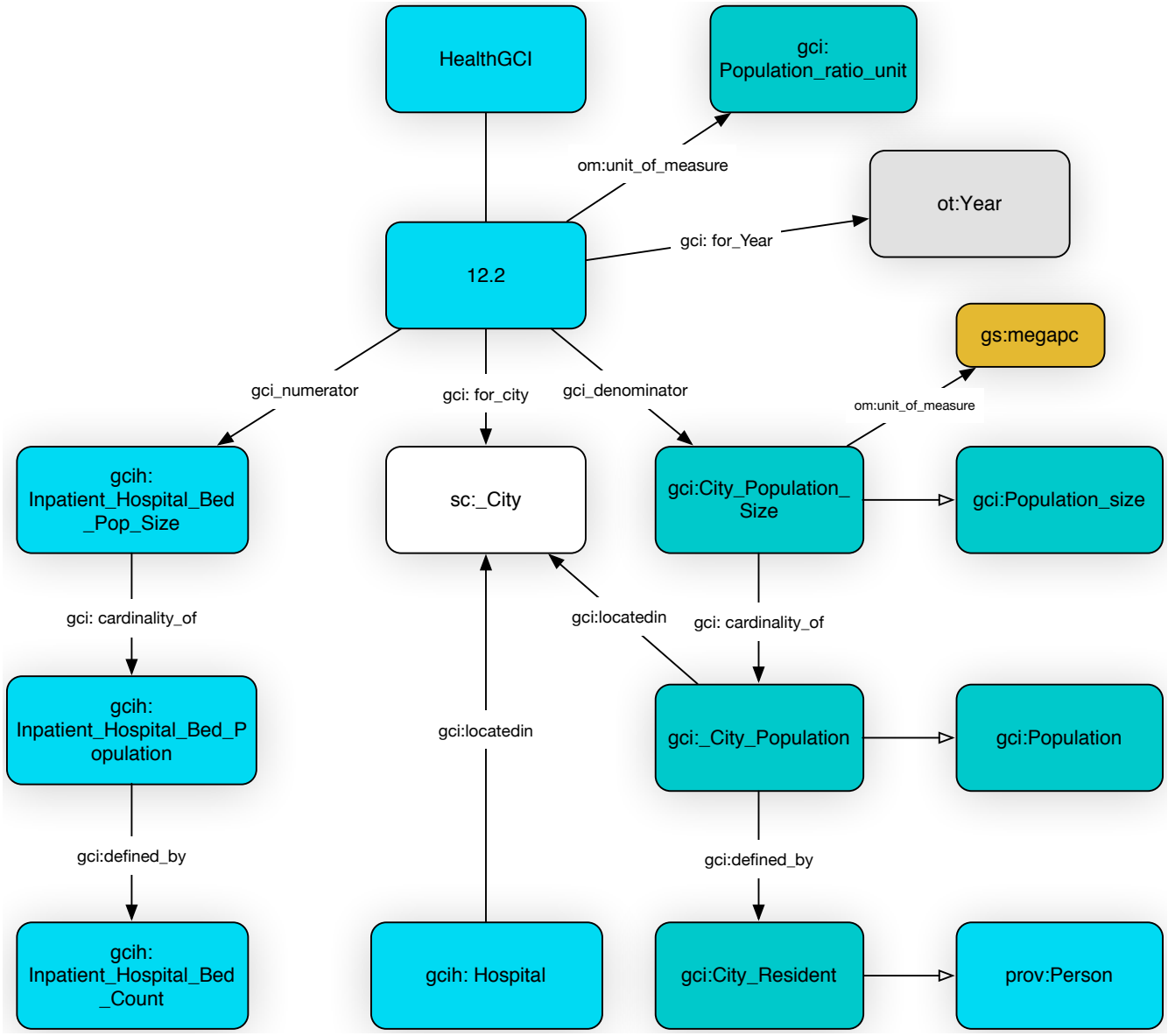


Figure 12

The "Inpatient_Hospital_Bed_Population defines the population of inpatient hospital beds.

Class	Property	Value Restriction
Inpatient_Hospital_Bed_Population	owl:subClassOf	gs:Population
	gs:defined_by	*gcih:Inpatient_Bed*
	gs:located_in	gci:City
	gci:for_time_interval	ot:DateTimeInterval

The "Inpatient_Hospital_Bed_Pop_Size" class offers a value for the number or in this case, the instances of "Inpatient_Hospital_Beds" in a hospital or city.

Class	Property	Value Restriction
Inpatient_Hospital_Bed_Pop_Size	owl:subClassOf owl:subClassOf	gci:population_size om:quantity
	defined_by for_city	Inpatient_Bed Exactly 1 City

5.3. Number of physicians per 100,000 (Indicator 12.3)

For the purpose of discussion, the following is a draft outline of the concepts and possible relationships that would be required to represent the indicator. The diagram that follows will offer a visual representation of the linked classes and their relationship with the existing GCI classes.

The sample Implementation of the 12.3 Indicator is shown below:

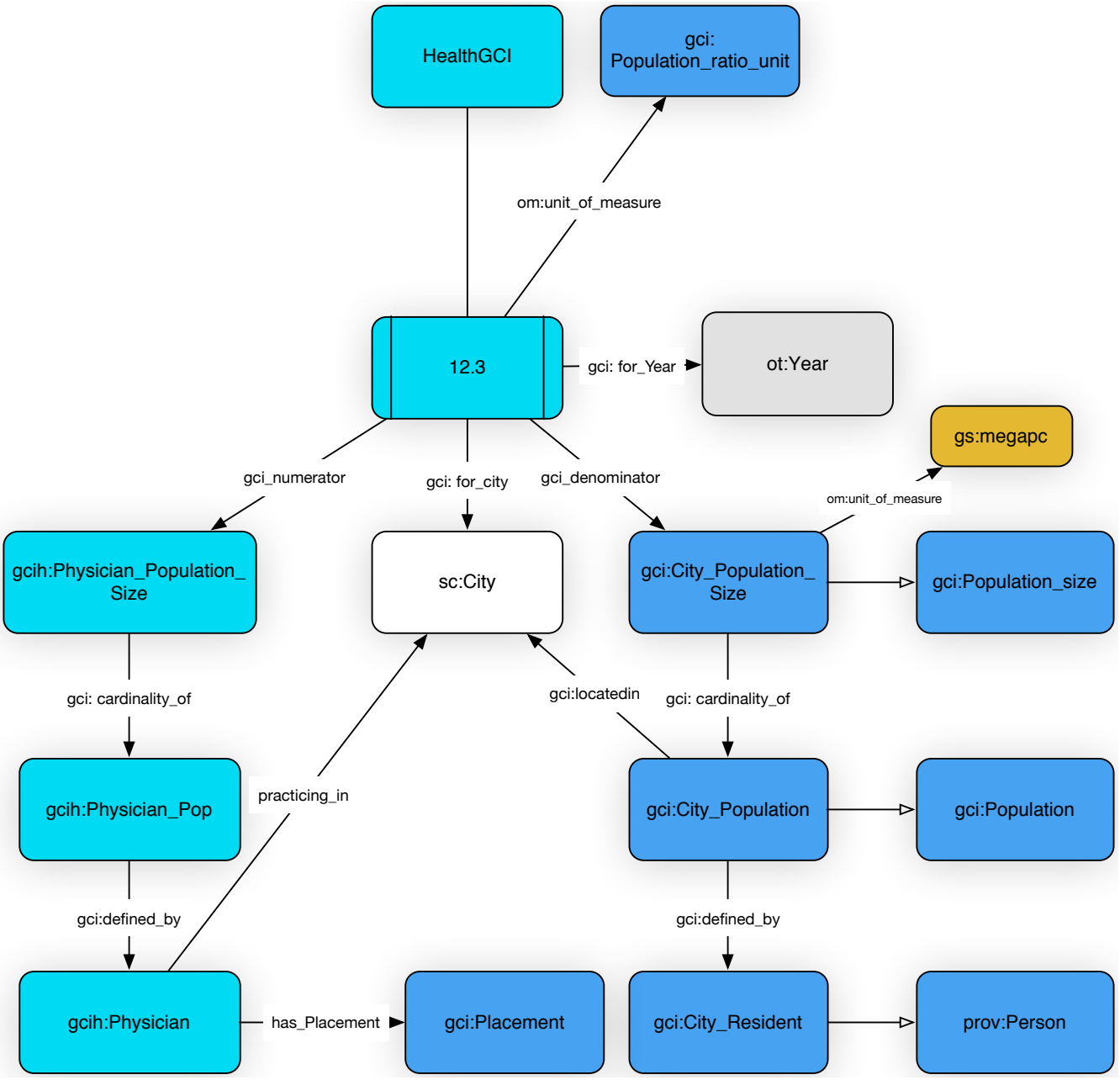


Figure 13

A "Placement" is adapted from the Education Indicators ontology by Fox, 2014, to provide an indication of if a "ProfessionalHealthCareProvider" works full time or not. As the actual definition of full time or part time is not provided, we set a minimum requirement for the physician to work at a "HealthcareFacility".

Class	Property	Value Restriction

Physician	subClassOf	ProfessionalHealthcareProvider
	has_Placement	12.3 Placement
	owl:equivalentClass	Doctor
Placement	owl:subClassOf	12.3 Placement
	works_At	min 1 HealthcareFacility
	days_Worked	Exactly 1 positiveInteger
	min_Days_Worked	Value 1
ProfessionalHealthcareProvider	has_License	min 1 License

5.4. Under age five mortality per 1,000 live births (12.4)

Core Indicator Requirements

The under age five mortality per 1000 live births shall refer to the probability of a child born in a specified year, dying before reaching the age of five, and shall be expressed as a rate per 1000 live births.

Preliminary Questions

1. (Factual) How many infants were born in (Cohort) year X?
2. (Factual) How many infants of (Cohort year X) die in year Y?
3. (Factual) What (cohort) is (infant X) a member of?
4. (Factual) What did (infant) X die of?
5. (Deduced) How many infants born in Year X are still alive after 5 years?

According to the organization that estimates mortality rates in different countries, a regression model is used to estimate this number for each country on an annual basis[49]. The estimation is supported by the UN Inter Agency Group for Child Mortality Estimation[50]. The source of the data is from "Civil Registration Systems".

When observing the data reported by different agencies on this indicator, the key concepts to be represented include, the number of infant deaths in a given year and the infant birth year (maximum 5 years before the current year, age five or less). The denominator simply represents the population of infants below age five.

[49] L. Alkema and J. R. New, "Global estimation of child mortality using a Bayesian B-spline bias-reduction method," vol. 8, no. 4, p. 22, 2013.
[50] http://www.childmortality.org

The indicator can be represented as such:

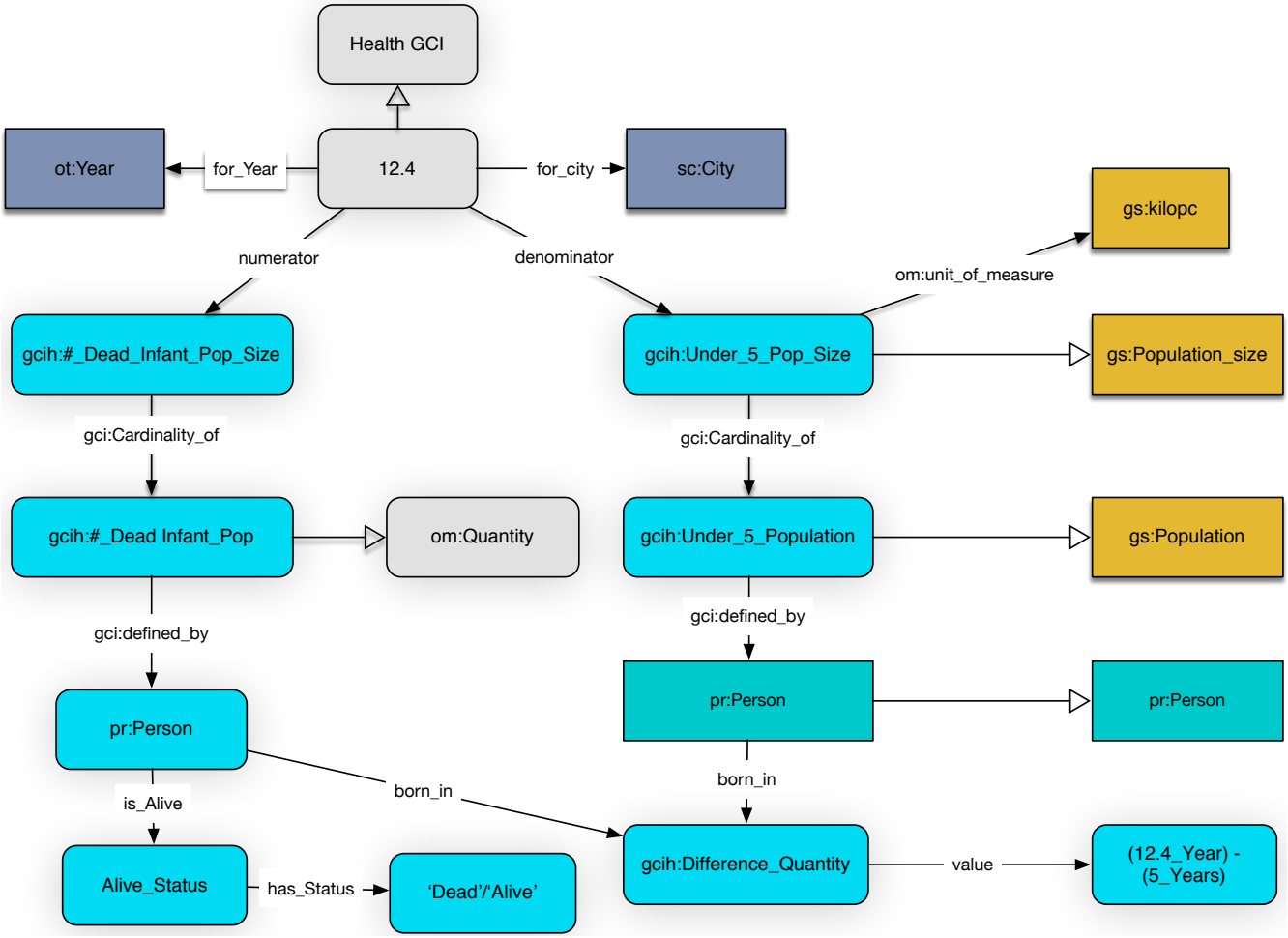


Figure 14: 12.4 (Under age five mortality per 1,000 live births)

5.5. Number of Nursing and Midwifery personnel per 100,000 population (12.5)

Competency Questions

1. (Factual) Is person X a nurse or a midwife?
2. (Factual) What type of nurse is person X?
3. (Factual) Is person X actively practicing?
4. (Factual) Does a nurse/midwife have a license?
5. (Factual) Was a nurse/midwifes' license issued by the state/provincial licensing body?
6. (Factual) From what educational institution has a nurse/midwife received her education?
7. (Deduced) Is the educational institution accredited?
8. (Factual) Is the nurse or midwife employed in the city?
9. (Factual) When did the nurse become certified?

Class	Property	Value Restriction
ProfessionalHealthcare Provider	owl:subClassOf	org:OrganizationAgent
	owl:subClassOf	sc:Person
Nurse	owl:subClassOf	HealthcareProfessional
	hasLicensure	exactly 1 NursingLicense
Midwife	owl:subClassOf	HealthcareProfessional
	hasLicensure	exactly 1 MidwiferyLicense

Sample Implementation of the 12.5 indicator is the same for 12.3. The main difference being the replacement of the “Physician/Doctor” concept with a “Nurse/Midwife” concept.

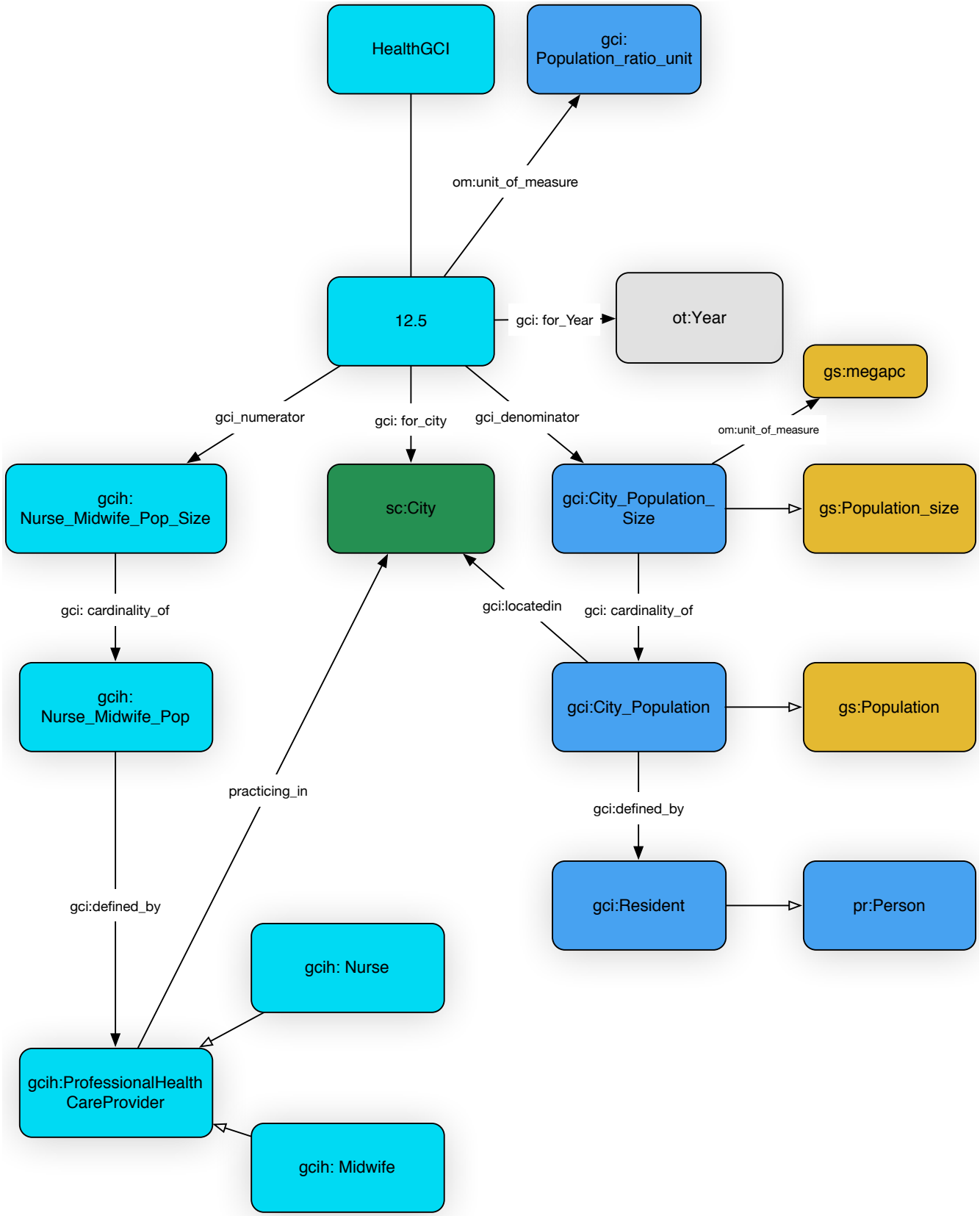


Figure 15: 12.5 Nurses/Midwives per 100,000

5.6. Number of Mental Health Practitioners per 100,000 population (12.6)

Classes and Properties

To be able to computationally represent the definitions of ISO 37120 education indicators, we need to add educational concepts not included in the core ontologies. We will begin to define the additional classes and they will be maintained within the GCI Healthcare Indicator Ontology at http://ontology.eil.utoronto.ca/GCI/Health/GCI-Healthcare.owl

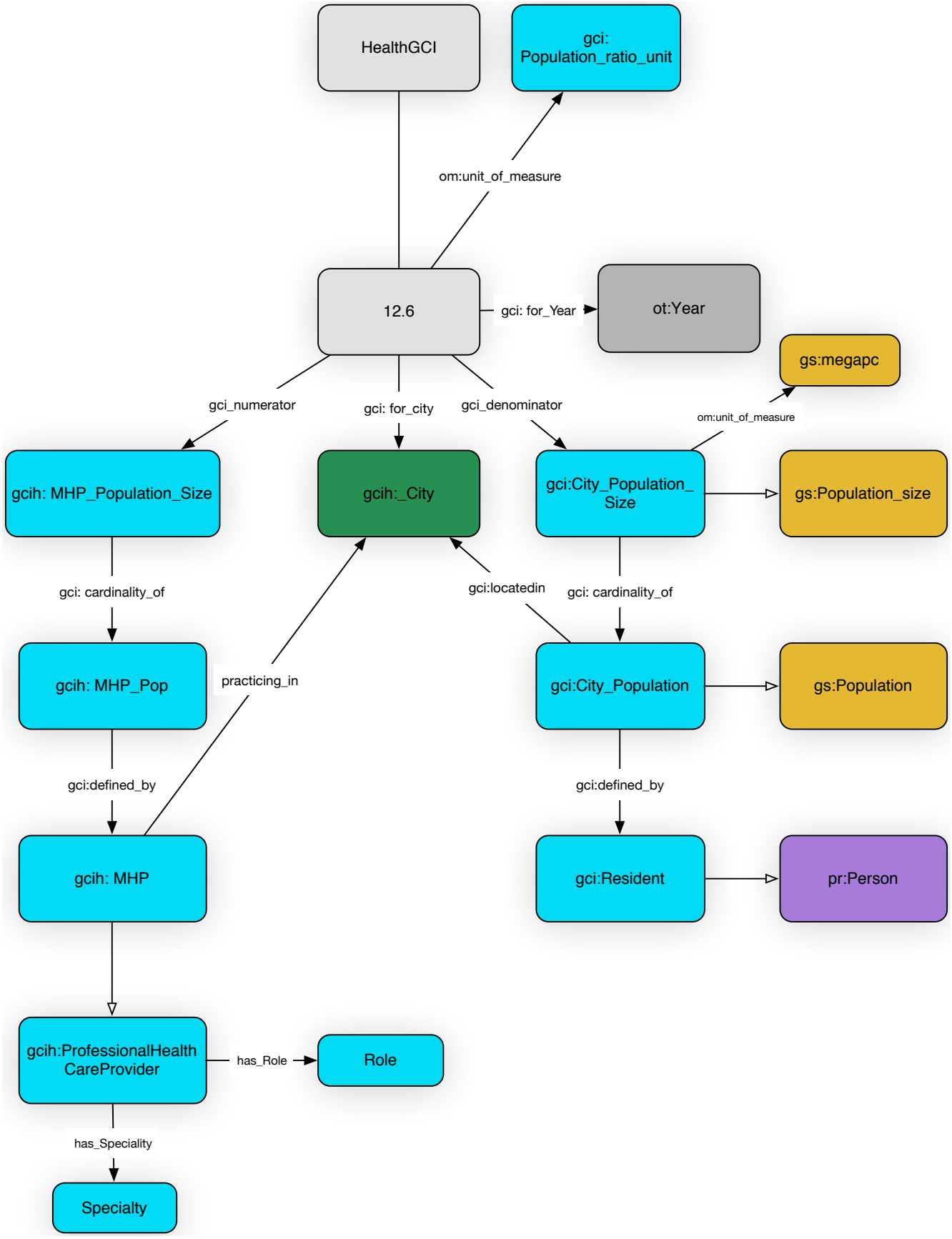

HealthGCI
gci:
Population_ratio_unit
om:unit_of_measure
12.6
gci: for_Year
ot:Year
gs:megapc
gci_numerator
gci: for_city
gci_denominator
om:unit_of_measure
gcih: MHP_Population_Size
gcih:_City
gci:City_Population_
Size
gs:Population_size
gci: cardinality_of
gci:locatedin
gci: cardinality_of
gcih: MHP_Pop
practicing_in
gci:City_Population
gs:Population
gci:defined_by
gci:defined_by
gcih: MHP
gci:Resident
pr:Person
gcih:ProfessionalHealth
CareProvider
has_Role
Role
has_Speciality
Specialty

Figure 16

5.7. Suicide rate per 100,000 population (12.7)

"This is a supporting indicator that is defined as the number of deaths "deliberately initiated and performed by a person in the full knowledge or expectation of its fatal outcome", according to the OECD[51].

Further to that definition, for the purpose of comparison, some key metrics to support comparability is based on intention of killing oneself being determined, the agency or person responsible for completing the death certificate, whether a forensic investigation in completed and the provisions for confidentiality of the cause of death[52]. The representation below accounts for the first two conditions.

[51] https://data.oecd.org/healthstat/suicide-rates.htm

[52] https://data.oecd.org/healthstat/suicide-rates.htm

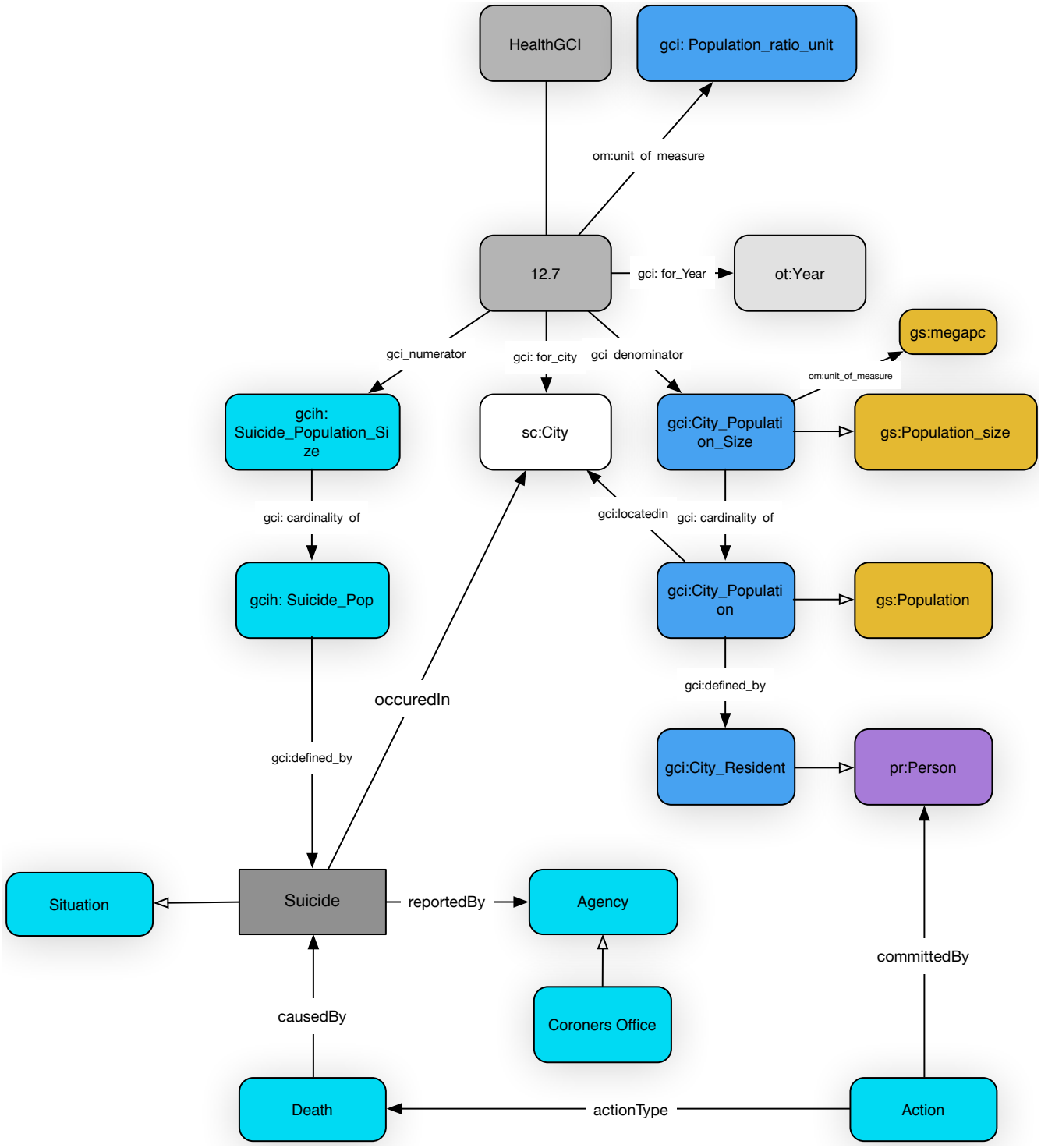

HealthGCI
gci: Population_ratio_unit
om:unit_of_measure
12.7
gci: for_Year
ot:Year
gs:megapc
om:unit_of_measure
gci_numerator
gci: for_city
gci_denominator
gcih: Suicide_Population_Size
sc:City
gci:City_Population_Size
gs:Population_size
gci: cardinality_of
gci:locatedin
gci: cardinality_of
gcih: Suicide_Pop
gci:City_Population
gs:Population
occuredIn
gci:defined_by
gci:defined_by
gci:City_Resident
pr:Person
Situation
Suicide
reportedBy
Agency
committedBy
causedBy
Coroners Office
Death
actionType
Action

Figure 17

As an alternative, the concept of suicide can be associated with a medical condition, so that it can be tied to a disease. In this case, we will swap the concept of suicide with death.

6. Evaluation

We will evaluate the Health ontology by testing its consistency and demonstrating that the ontology is able to answer the competency questions defined in Section 2. To do so, we will be using data from the City of Toronto to answer the competency questions.

For the purposes of the evaluation, the second indicator, Number of in-patient hospital beds per 100,000 Population (ISO 37120:12.2) is used as an example. To achieve this, we will first define example instances below. The instances provide background information on the City of Toronto. Next, we define the instances of concepts related to the 12.2 indicator.

The following are the URIs for each of the ontologies imported into the GCI Health ontology

Ontology Prefix	URI	Description
Isoh	http://ontology.eil.utoronto.ca/GCI/ISO37120/Health.owl#	The ISO37120 health indicators defined in section 7
gcih[53]	http://ontology.eil.utoronto.ca/GCI/ISO37120/Health.owl	The healthcare ontology
gci	http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Foundation.owl#	The Foundation ontology defined in (Fox, 2013)
ot	http://www.w3.org/TR/owl-time/	The Time ontology
prov	https://www.w3.org/TR/prov-o/	Provenance ontology
om	http://www.wurvoc.org/vocabularies/om-1.8/	Measurement ontology
org	http://ontology.eil.utoronto.ca/organization.html	Organization ontology
res	Residence ontology as defined by Fox and Forde (2015)	

Instance	Property	Value
gn:6251999	rdfs:label	Canada
	rdfs:type	gn: Feature
	rdfs:type	sc:Country
gn:6093943	rdfs:label	"Ontario"
	rdfs:type	gn: Feature
	rdfs:type	sc: Province
gn:6167865	rdfs:label	"Toronto"

[53] The GCI Health ontology is represented by the prefix 'gcih'

	rdfs:type	gn:Feature
	rdfs:type	sc:City

The instances that instantiate the 12.2 indicator are defined in the following table:

Instance	Property	Value
12.2_ex (instance of 12.2)	rdfs:type	iso:12.2
	gci:numerator	12.2 Inpatient_Hospital_Bed_Pop_Size
	gci:denominator	12.2 City_Population_Size
	gcih:for_Year	12.2_Year
	gci_for_city	gn:6167865
12.2_ex_value	rdfs:type	om:Measure
	om:numerical_value	200
	om:unit	gci:population_ratio_unit

The following illustrates how the competency questions for ISO 37120 Health indicators are implemented in SPARQL.

1. (Factual) What city is the indicator for?

   SELECT ?city WHERE {

   12.2_ex gci:for_city ?city
   }

   Output:

   'Toronto'

2. (Factual) For what year is the hospital bed indicator being measured?

   SELECT ?year WHERE {
   12.2_ex gcih:for_Year ?year
   }

   Output:

   '2017'

3. (Factual) What type of bed is hospital bed X?

SELECT ?HospitalBedType WHERE
{12.2_HospitalBed gcih:hospitalBed_type ?HospitalBedType }

Output:

?HospitalBedType
'Day Care Bed'

4. How many hospital beds of type X does Hospital Y have?

Select COUNT ?HospitalBed AS ?num) WHERE
{ ?HospitalBed isoh:hospitalBed_type ?HospitalBedType
?HospitalBedType isoh:hospitalBed_Type: Wakeup_Bed
isoh:HospitalBedType: Wakeup_Bed

6.1. FILTER (?hospital_name =”Toronto General”)

}

Output: '417'

5. (Factual) How many outpatient beds does hospital X have?

Select COUNT ?HospitalBed AS ?num) WHERE
{ ?HospitalBed gcih:hospitalBed_type gcih:outpatient_Bed
?HospitalBedType gcih:hospitalBed_Type: Outpatient_Bed
FILTER (?hospital_name =”Toronto West”)
}

Output: '256'

6. (Factual) Is hospital X public or private?

SELECT ?Hospital WHERE
{
?Hospital org:has_Ownership ?Ownership
FILTER (?hospital_name =”Toronto West”)

}

Output: 'Public'

The diagram below provides an overview of the ontologies imported into the GCI Health ontology. By outlining this hierarchy, we are able to verify if the imported ontologies conform to the ontology specifications

7. Conclusions

The GCI Health Ontology represents the Health concepts used in the definition of the ISO37120 Health indicators. The objectives of this work were threefold, first to define a broad ontology enabling the definition of the ISO 37120 Health Indicators, with definitions for classes within the ontology as well as the properties associated with the classes. Second, this work outlines the implementation of the ontology using city data on the Semantic Web. Finally, the objective was to enable the consistent comparison of indicators temporally across cities.

These objectives were met through the creation of the following ontologies:

- Licensure
- ProfessionalHealthcareProvider
- Quality of Life Ontology

The following existing ontologies were utilized to help represent the ISO 37120 indicators:

- Residency
- Education

8. Acknowledgements

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10. Appendix

- The Global City Indicator Foundation ontology can be found in: http://ontology.eil.utoronto.ca/GCI/Foundation/GCI-Founation.owl
- The Global City Indicator Education ontology can be found in: http://ontology.eil.utoronto.ca/GCI/Health/GCI-Health.owl
- URIs for all of the ISO37120 indicators can be found in:http://ontology.eil.utoronto.ca/ISO37120.owl
- Definitions of the ISO37120 education indicators, using the GCI Foundation and health ontologies can be found in:http://ontology.eil.utoronto.ca/GCI/ISO37120/Health.owl

Other ontologies used by the Foundation and Innovation ontologies are:

- Geonames Ontology
  - gn: http://sws.geonames.org/
- Schema Ontology
  - sc: http://schema.org/
- The International Contact Ontology
  - ic: http://ontology.eil.utoronto.ca/icontact.owl
- The Time Ontology
  - ot: http://www.w3.org/2006/time
- The Provenance Ontology
  - prov: http://www.w3.org/ns/prov
- The Measurement Ontology
  - om: http://www.wurvoc.org/vocabularies/om-1.8/
- The Organization Ontology
  - org: http://ontology.eil.utoronto.ca/organization.owl
- The Statistics Ontology
  - gs: http://ontology.eil.utoronto.ca/govstat.owl
- Trust and validity ontology
  - kp: http://ontology.eil.utoronto.ca/trust.owl