TALLINNA TEHNIKAÜLIKOOL
Infotehnoloogia teaduskond

Marina Ivanova 211715IABM

Kliiniliste terminoloogiate haldamise optimeerimine: Terminoloogiaserverite analüüs, CTS2 rakendamine PostgreSQL-is ja teisendamine FHIR ressurssidele

Magistritöö

Juhendaja: Igor Bossenko
Doktorant

Kaasjuhendaja: Gunnar Piho
Doktorikraad

Tallinn 2024

Autorideklaratsioon

Kinnitan, et olen koostanud antud lõputöö iseseisvalt ning seda ei ole kellegi teise poolt varem kaitsmisele esitatud. Kõik töö koostamisel kasutatud teiste autorite tööd, olulised seisukohad, kirjandusallikatest ja mujalt pärinevad andmed on töös viidatud.

Autor: Marina Ivanova

08.01.2024

Annotatsioon

Antud magistritöö rõhutab vajadust lahenduste järele, mis võimaldaksid sujuvat kliinilise terminoloogia vahetust, tagades seeläbi tervishoiusüsteemide tõhusa suhtluse ja koostalitlusvõime. Kliinilise terminoloogia standardiseerimisel ja haldamisel on terminoloogiaserveritel keskne roll, tagades järjepideva suhtluse ja teadmiste jagamise. Töö annab ülevaate olemasolevatest kliinilise terminoloogiaserveritest, keskendudes nende omadustele ja piirangutele. Hinnatakse mitme olulise terminoloogiaserveri tugevusi ja nõrkusi. Töö tulemused kajastavad terminoloogiaserverite praegust seisundit, tuues esile olemasolevate lahenduste piirangud ja puudused. Selle tulemusena jõutakse esimese osa lõpus järeldusele, toetades uue ja täiustatud terminoloogiaserveri uurimise ja väljatöötamise vajadust. Töö teises pooles käsitletakse Common Terminology Services 2 (CTS2) standardi rakendamist PostgreSQL andmebaasis. Arutelu keskendub CTS2 integreerimise keerukusele PostgreSQL-iga, uurides sellega seotud väljakutseid ja leitud lahendusi. Lisaks annab töö ülevaate CTS2 teisenemisest HL7 Fast Healthcare Interoperability Resources (FHIR) standardi ressurssidele. Lugejatele antakse ülevaade rakendamise tehnilistest aspektidest, praktilistest kaalutlustest ning võimalikest mõjudest tervishoiuandmete haldamisele. Uurimise eesmärk on juhendada arendajaid, tervishoiu IT-spetsialiste ja sidusrühmi CTS2 edukal integreerimisel PostgreSQLi, tagades samal ajal ühilduvuse HL7 FHIR-i ressurssidega, edendades lõpuks paremat koostalitlusvõimet tervishoiuvaldkonnas.

Lõputöö on kirjutatud eesti keeles keeles ning sisaldab teksti 57 leheküljel, 5 peatükki, 4 joonist, 1 tabelit ja 3 lisa. Lisa 2 ja Lisa 3 sisaldavad artikleid, mille põhjal lõputöö koostatud on.

Abstract

Optimizing the management of clinical terminologies: Analysis of terminology servers, implementation of CTS2 in PostgreSQL and conversion to FHIR resources

This master's thesis highlights the need for robust solutions to facilitate the exchange of clinical terminology, ensuring seamless communication and interoperability between healthcare systems. Terminology servers are central to the standardisation and management of terminology, ensuring consistent communication and knowledge sharing. This work provides a overview of the challenges and limitations of existing clinical terminology servers. We evaluate the strengths and weaknesses of terminology servers. The results reveal important insights into the current landscape of terminology management solutions, revealing limitations and potential gaps. As a result, the first part of the paper ends with an argument for the need to research and develop a new advanced terminology server solution. The second paper deals with the implementation of the Common Terminology Services 2 (CTS2) standard in PostgreSQL. The discussion covers the complexities of integrating CTS2 with PostgreSQL, exploring the challenges and solutions encountered during the process. In addition, the work provides an overview of the conversion of CTS2 to the resources of the HL7 Fast Healthcare Interoperability Resources (FHIR) standard. Readers will gain insight into the technical aspects of implementation, practical considerations, and potential impact on healthcare data management. This research aims to guide developers, healthcare IT professionals and stakeholders in leveraging CTS2 in PostgreSQL while ensuring compatibility with HL7 FHIR resources, ultimately promoting better interoperability in the landscape of healthcare.

The thesis is written in Estonian and is 57 pages long, including 5 chapters, 4 figures, 1 table and 3 appendixes. Appendix 2 and Appendix 3 contain the articles this thesis is based on.

Lühendite ja mõistete sõnastik

API	Application Programming Interface
ClaML	Classification Markup Language
CRUD	Create, Read, Update and Delete
CSV	Comma Separated Values
CTS2	Common Terminology Services 2
DSRM	Design Science Research Methodology
DTS	Distributed Terminology System
EHR	Electronic Health Record
FHIR	Fast Healthcare Interoperability Resources
FSH	FHIR Shorthand
HL7	Health Level 7
ICD	International Classification of Diseases
IT	Information Technology
JSON	JavaScript Object Notation
LOINC	Logical Observation Identifiers, Names, and Codes
REST	Representational State Transfer
RF2	Release Format 2
SNOMED CT	Systematized Nomenclature of Medicine Clinical Terms
SQL	Structured Query Language
STC	Standardized Terminology Classifications
TS	Terminology Server
TSV	Tab Separated Values
XML	Extensible Markup Language

Sisukord

1 Sissejuhatus **9**
1.1 Taust 9
1.1.1 Tervishoiu andmevahetuse standardid 10
1.1.2 Standardiseeritud kliinilise terminoloogia klassifikaatorid 10
1.1.3 HL7 FHIR terminoloogiamoodul 10
1.1.4 Terminoloogiaserver 11
1.2 Probleem 11
1.3 Eesmärk 12

2 Metoodika **13**

3 Tulemused **14**
3.1 Terminoloogiaserveri kriteeriumid 14
3.2 Olemasolevate terminoloogiaserverite ülevaade 15
3.2.1 Ontoserever 15
3.2.2 Snowray 16
3.2.3 Rhapsody 16
3.2.4 TermSpace 16
3.2.5 Snowstorm 16
3.2.6 Hermes 17
3.2.7 Apelon DTS 17
3.3 Terminoloogiaserverite vastavus kriteeriumidele 17
3.4 CTS2 kontseptuaalne mudel 18
3.5 HL7 FHIR terminoloogia kontseptuaalne mudel 19
3.6 CTS2 ja HL7 FHIR kontseptuaalsete mudelite võrdlus 19
3.7 CTS2 kontseptuaalsel mudelil põhinev andmebaasi disain 19
3.8 CTS2 andmemudeli teisendamine HL7 FHIR terminoloogia ressurssidele 21

4 Analüüs ja järeldused **22**

5 Kokkuvõte **25**

Kasutatud kirjandus **27**

Lisa 1 – Lihtlitsents lõputöö reprodutseerimiseks ja lõputöö üldsusele kättesaadavaks tegemiseks **29**

Lisa 2 – Comparative analysis of clinical terminology servers: a quest for an improved solution **30**

Lisa 3 – TermX - Bridging the Gap: Implementing CTS2 and FHIR compatible Terminology Server **44**

Jooniste loetelu

1 CTS2 kontseptuaalne mudel. 18
2 FHIR terminoloogia kontseptuaalne mudel. 19
3 Koodisüsteemi ressursi TermX andmebaasi disain. 20
4 LOINC-il põhinev koodisüsteemi ressursi näide. 20

Tabelite loetelu

1 Terminoloogiaserverite vastavus kriteeriumidele. 17

1. Sissejuhatus

Käesolev lõputöö koosneb kahest ingliskeelsest artiklist (Lisa 2-3) ja laiendatud eestikeelsest kokkuvõttest.

Esimene artikkel, "Comparative Analysis of Clinical Terminology Servers: A Quest for an Improved Solution", on esitatud MIPRO 2024 konverentsile, mis leiab aset Opatijas 20. - 24. maini 2024. Töö autor on artikli esimene autor, ja artikkel on kirjutatud LaTeX-i kasutades, olles 13 lehekülge pikk. Lisa 2 esitab artikli esmase versiooni, mille tähtaeg oli 8. jaanuar 2024. Seisuga 3. jaanuar 2024 on artikkel konverentsile esitatud ja ootab publitseerimiseks vastuvõtmise protsessi.

Teine artikkel, "TermX - Bridging the Gap: Implementing CTS2 and FHIR compatible Terminology Server", on samuti esitatud MIPRO 2024 konverentsile, toimudes Opatijas 20. - 24. maini 2024. Töö autor on artikli esimene autor, ja see on kirjutatud LaTeX-i kasutades, ulatudes 12 leheküljeni. Lisa 3 kujutab artikli esmase versiooni, mille esitamise tähtaeg oli 8. jaanuar 2024. Seisuga 3. jaanuar 2024 on ka see artikkel konverentsile esitatud ja ootab publitseerimiseks vastuvõtmise protsessi.

Käesolev laiendatud eestikeelne kokkuvõte annab ülevaate mõlema artikli käsitletavatest probleemidest, nende eesmärkidest, kasutatud metoodikast ja toob esile informatsiooni uuritavate objektide kohta. Lisaks esitatakse mõlema artikli tulemused ja järeldused.

1.1 Taust

Digitaalse tervishoiu tänapäevases kontekstis kerkivad esile kliiniliste andmete tõhusa vahetamise ja haldamise tungiv nõue. Tervishoiuprotsesside digitaliseerimine on toonud kaasa mitmekesise kliinilise terminoloogia ja andmestruktuuride kujunemise. Sujuva koostalitlusvõime saavutamine erinevate süsteemide vahel nõuab ühtse keele loomist kliiniliste kontseptsioonide väljendamiseks. Digitaalse meditsiini edu sõltub koostalitlusvõimest, rõhutades seeläbi vajadust standardiseeritud kliiniliste terminoloogiate järele [1]. Selles kontekstis mängivad kliinilise terminoloogia serverid keskset rolli, pakkudes standardiseeritud raamistikku kliinilise terminoloogia selgitamiseks [2].

1.1.1 Tervishoiu andmevahetuse standardid

HL7 FHIR – HL7 Fast Healthcare Interoperability Resources

HL7 FHIR [3] on standard, mis on loodud tervisevaldkonna andmete vahetamiseks ja jagamiseks. Selle eesmärk on hõlbustada suhtlust erinevate tervishoiuinfosüsteemide vahel, võimaldades efektiivsemat andmevahetust erinevate tervishoiuasutuste, rakenduste ja seadmete vahel. FHIR kasutab kaasaegseid veebitehnoloogiaid, sealhulgas RESTful API-sid (Representational State Transfer), JSON-i andmeformaati ja standardseid veebiprotokolle. FHIR väljaanded esindavad standardi erinevaid versioone, kus iga väljaanne pakub uusi võimalusi andmete esitamiseks ja terviseinfosüsteemide arendamiseks.

CTS2 – Common Terminology Services 2

CTS2 [4] on standard, mis on loodud terviseinfosüsteemides ja tervishoiuandmete jagamises kasutatavate terminoloogiate ja kontseptsioonide haldamiseks. CTS2 eesmärk on tagada ühtne arusaam tervishoiuandmete tähendusest, pakkudes universaalset kontseptuaalset andmemudelit.

1.1.2 Standardiseeritud kliinilise terminoloogia klassifikaatorid

Tervishoiu valdkond tugineb mitmesugustele standardiseeritud klassifikaatoritele. Need klassifikaatorid koosnevad standardiseeritud terminitest ja koodidest, mida kasutatakse meditsiiniliste mõistete tähistamiseks. Standardiseeritud terminoloogia klassifikaatorid (STC), nagu SNOMED CT [5], LOINC [6] ja ICD [7], võimaldavad tervishoius sujuvat ühtset keelt, et hõlbustada suhtlust ja andmevahetust [8, 9].

1.1.3 HL7 FHIR terminoloogiamoodul

HL7 FHIR terminoloogiamoodul [10] on osa FHIR standardist, keskendudes terviseandmete terminoloogia haldamisele. See moodul võimaldab standardiseeritud viisil esitada ja vahetada tervishoiuga seotud mõisteid, kontseptsioone ja terminoloogiat. Terminoloogiamoodul hõlmab mitmeid ressursse ja operatsioone, mis on olulised terminoloogia haldamiseks.

Ressursid:

- *CodeSystem* kirjeldab mõisteid, nende määratlusi ja suhteid ning muid olulisi omadusi, nagu koodide süsteemi identifikaator ja versioon.

- *ValueSet* koondab kokku kogumiku väärtusi, näiteks koode, teatud kontekstis või otstarbeks, hõlbustades nende ühtset kasutamist.
- *ConceptMap* seob omavahel erinevate terminoloogiate mõisted, võimaldades andmete tõlkimist ühest süsteemist teise.
- *NamingSystem* ressurss aitab identifitseerida ja kirjeldada erinevaid terminoloogiasüsteeme, millest koodid võivad pärineda.

Operatsioonid:

- *Expand* operatsioon võimaldab laiendada ValueSet ressurssi, andes üksikasjaliku nimekirja sellele kuuluvatest koodidest.
- *Validate-code* operatsioon võimaldab kontrollida, kas konkreetne kood vastab CodeSystem ressursile määratletud reeglitele.
- *Lookup* operatsioon võimaldab otsida üksikasjalikke andmeid konkreetse koodi kohta, näiteks selle tähendus ja atribuudid.
- *Translate* operatsioon võimaldab tõlkida mõisteid ühest terminoloogiast teise, kasutades ConceptMap ressurssi.

1.1.4 Terminoloogiaserver

Terminoloogiaserver (TS) on kliinilise terminoloogia kontekstis spetsiaalne tarkvararakendus, mis on loodud hõlbustama standardiseeritud kliiniliste sõnavarade loomist, korraldamist ja jagamist tervishoiuvaldkonnas. Terminoloogiaserver pakub struktureeritud keskkonda, kus tervishoiutöötajad, teadlased ja süsteemiarendajad saavad standardiseeritud kliinilistele terminitele juurde pääseda, neid värskendada ja neisse panustada [2].

1.2 Probleem

Magistritöö põhirõhk on tervishoiusektoris esineval probleemil, kus puudub universaalne ja kättesaadav kliinilise terminoloogia haldamise süsteem. Praegusel hetkel kasutatakse mitmesuguseid terminoloogiaservereid, millel on spetsiifilised funktsionaalsused ja erinevad eesmärgid. Selle mitmekesisuse tagajärjel ilmnevad mitmed takistused, sealhulgas koostalitlusvõime puudumine, andmete ühildamatus ja raskused tarkvaraarenduses. Lisaks on nende lahenduste rohkus tekitanud olulise väljakutse tervishoiutöötajatele, teadlastele ja süsteemiarendajatele – valida keerulises olukorras optimaalne kliinilise terminoloogiaserver, mis vastaks konkreetsetele nõuetele ja kriteeriumidele.

1.3 Eesmärk

Antud magistritöö eesmärk on uurida olemasolevate meditsiiniliste terminoloogiaserverite funktsionaalsusi, tõhusust ja puudujääke ning põhjaliku analüüsi tulemusena välja töötada uus kliinilise terminoloogiaserveri lahendus. Uus lahendus peaks suutma paremini toetada meditsiinilise terminoloogia tõhusat vahetust ja integreerimist tervishoiu infosüsteemides..

2. Metoodika

Magistritöö esimese osa jaoks kasutatav metoodika põhineb kirjanduse uurimisel ja kriteeriumide valimisel, mis määratlevad tõhusa kliinilise terminoloogiaserveri. Selle esialgse etapi eesmärk oli luua alus järgnevaks terminoloogiaserverite võrdlemiseks. Määratletud kriteeriumide kogumi abil keskendus meie töö kliinilise terminoloogiaserverite andmete kogumisele, tavaliselt kasutatavate terminoloogiaserverite tuvastamisele, iga terminoloogiaserveri lühiülevaatele ja sellele järgnenud põhjalikku võrdlusele. Olemasoleva kirjanduse kogumisel kasutasime otsingusõnu nagu *clinical terminology*, *clinical terminology server*, *clinical terminology standard*, *medical terminology server* ja *FHIR terminology*. Lisaks konsulteerisime tervishoiutöötajatega, süvenesime valdkonna standarditesse ja kaalusime nende terminoloogiaserverite levimust praegustes tervishoiutavades. Seejärel viidi eelnevalt määratletud kriteeriumide alusel läbi valitud kliinilise terminoloogia serverite süstemaatiline võrdlus.

Järgides disainiteaduse uurimismetoodika (DSRM) põhimõtteid, algatasime TermX Serveri disaini- ja arendusprotsessi. Terminoloogiaserverit koostades kasutasime ühilduvuse ja koostalitlusvõime tagamiseks standardeid, nagu Fast Healthcare Interoperability Resources (HL7 FHIR) [3] ja Common Terminology Services 2 (CTS2) [4]. Oluliseks sammuks oli sobiva andmebaasihaldussüsteemi valimine, mille tulemusena valisime relatsioonilise andmebaasihaldussüsteemi PostgreSQL [11], et see ühilduks CTS2 ja FHIR-iga. PostgreSQL-i CTS2 kontseptuaalse mudeli integreerimisel keskendusime FHIR terminoloogiamooduli nõuete ja piirangute kaasamisele, et vastata kehtestatud standarditele. CTS2 kontseptuaalse mudeli integreerimisel võrdlesime seda FHIR kontseptuaalse mudeliga ja töötasime välja teisendusprotsessi. Viisime läbi FHIR standardi põhiseid testimis- ja valideerimisprotsesse, et tagada CTS2 ja FHIR-i sujuv integreerimine. Arendus protsessis olid kasutusel: programmeerimiskeeled, nagu Python [12], Java [13] ja JavaScript [14]; tarkvaraarenduse keskkond IntelliJ IDEa [15]; koodihaldustarkvara GitLab [16]; raamistikud, nagu Angular [17] ja Micronaut [18].

3. Tulemused

3.1 Terminoloogiaserveri kriteeriumid

Kliinilise terminoloogiaserveri hindamise olulised kriteeriumid peaksid hõlmama erinevaid aspekte, et tagada tõhusus ja sobivus tervishoiuasutustele. Valisime terminoloogiaserverite võrdlemiseks järgmised kriteeriumid:

- *Standardiseeritud terminoloogia klassifikaatorite tugi*
  Kliinilise terminoloogiaserveri hindamisel on oluline kriteerium nende toetus standardiseeritud klassifikaatoritele, nagu SNOMED CT [5] ja LOINC [6]. Need standardid on olulised, kuna tagavad järjepidevuse ja koostalitlusvõime meditsiiniliste mõistete esitamisel. [19, 20]
- *Terminoloogia haldamine: CRUD operatsioonid*
  Tõhusat terminoloogiat (CodeSystem, Concept, ValueSet, ConceptMap) hinnatakse CRUD (Create, Read, Update, Delete) operatsioonide rakendamisega. See kriteerium tagab, et terminoloogiaserver võimaldab meditsiiniliste terminite sujuvat manipuleerimist, kajastades kliiniliste teadmiste muutusi ja uuendusi. [1, 2]
- *Terminoloogia import*
  Võimalus importida terminoloogiaid sellistest vormingutest nagu CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC ja SNOMED RF2 on praktiline kriteerium kasutatavuse parandamiseks ja väliste andmeallikate terminoloogiaserverisse integreerimise hõlbustamiseks. [21]
- *HL7 FHIR terminoloogiamooduli ressursid ja operatsioonid*
  HL7 FHIR terminoloogiamooduli ressursside tugi on tänapäevaste koostalitlusvõime standarditega vastavusse viimiseks hädavajalik. Need ressursid võimaldavad vahetada standardiseeritud tervishoiu andmeid. Terminoloogiamooduli operatsioonid võimaldavad rakendada standartiseerituid otsinguid, kontrolle ja lisa funktsionaalsusi. [9]
- *Sisemine andmemudel*
  Sisemine andmemudel on kliinilise terminoloogiaserverite põhikriteerium, kuna see toetab koostalitlusvõimet, järjepidevust, semantilist selgust ja kohanemisvõimet standarditega, mis on vajalikud tõhusaks tervishoiu andmete vahetamiseks laiemas ökosüsteemis. Põhinedes laialdaselt tunnustatud standarditel, nagu CTS2 või ontoloogia, hõlbustab standardiseeritud sisemine andmemudel semantilist koostalitlusvõimet, pakkudes kliiniliste kontseptsioonide esitamiseks ühise semantilise

aluse. [4]

- *Versioneerimise võimalus*
  Versioonide koostamine tagab andmete järjepidevuse ja annab ajaloolise perspektiivi meditsiinistandardite arengust. [1]
- *Mitmekeelne terminoloogia*
  Mitmekeelne terminoloogia tugi on väga oluline ülemaailmse koostalitlusvõime edendamiseks. See tagab, et terminoloogia definitsioone ja meditsiinilisi mõisteid saab täpselt esitada mitmes keeles. [1, 2]
- *Veebi liides*
  Kliinilise terminoloogiaserverite juurdepääsetavus ja kasutajasõbralikkus on tänapäeva digitaalses tervishoiukeskkonnas ülimalt tähtsad. Kasutajasõbralik mitmekeelne veebiliides hõlbustab tervishoiutöötajate terminoloogiasüsteemiga suhtlemist ja selles navigeerimist. [21]
- *Litsentsi tüüp*
  Litsentsi tüübi valimine, olgu see siis kommertslik või avatud lähtekoodiga, on kriitiline kriteerium, mis mõjutab oluliselt kliinilise terminoloogiaserveri kasutuselevõttu ja jätkusuutlikkust. Avatud lähtekoodiga lahendused soodustavad koostööd, läbipaistvust ja kogukonnapõhist arengut, mis omakorda võib viia laiaulatusliku kasutuselevõtuni. Võrreldes sellega võivad kommertslikud tooted pakkuda täiendavaid funktsioone, tuge ning teenuseid. Litsentsitüübi hindamine on kriitilise tähtsusega, et mõista terminoloogiaserveri kulusid, paindlikkust ja selle pikaajalist elujõulisust tervishoiu ökosüsteemis. [2]

3.2 Olemasolevate terminoloogiaserverite ülevaade

Tervishoiu dünaamilisel maastikul pakuvad mitmekesised kliinilise terminoloogiaserverid ainulaadseid funktsioone ja võimalusi, andes igaüks oma panuse pidevalt arenevasse ökosüsteemi.

3.2.1 Ontoserever

Ontoserver on sündikaatterminoloogiaserver, mis on loodud hõlbustama biomeditsiiniliste terminoloogiate tõhusat haldamist ja levitamist. Ontoserveri peamine eesmärk on pakkuda tsentraliseeritud platvormi biomeditsiiniliste terminoloogiate salvestamiseks, otsimiseks ja levitamiseks, tagades standardiseeritud suhtluse ja koostalitlusvõime tervishoiu ja biomeditsiiniliste uuringute valdkondades. Ontoserveri kriitilised omadused hõlmavad selle võimet sünteesida terminoloogiat standardsel viisil, tagades järjepidevuse ja täpsuse erinevates olukordades. Sündikatsioonimudel toetab ka terminite dünaamilist värskendamist, tagades kasutajatele juurdepääsu kõige värskemale ja asjakohasemale teabele. [22, 23]

3.2.2 Snowray

Snowray esindab veebipõhist lahendust, mis tõhusalt haldab kvaliteetseid terminoloogiaandmeid, eelkõige toetades meditsiiniterminolooge ressursside sujuval loomisel ja haldamisel. Platvorm võimaldab kasutajatel luua uusi ressursse või importida olemasolevaid. Snowray kasutajad saavad laiendada ja hooldada ressursse lihtsasti kasutatava veebiliidese abil. Lisaks rahvusvahelistele standarditele juurdepääsule pakub Snowray funktsioone ressursside koostamiseks ja kujundamiseks algusest peale. Kasutajad saavad teha muudatusi või osaleda aruteludes, kasutades Snowray sisseehitatud ülesannete haldamise süsteemi, mis võimaldab konkreetseid ressursse puudutavate ülesannete loomist. [24]

3.2.3 Rhapsody

Rhapsody Semantic pakub ulatuslikku tööriistakomplekti semantilise koostalitlusvõime saavutamiseks läbi tõhusa terminoloogiahalduse. See on võimalik integreerida sujuvalt olemasolevatesse rakendustesse või kasutada iseseisva lahendusena. Rhapsody hõlmab sisu- ja alamhulgateeki, automaatseid teisendamisvõimalusi ning universaalset sirvimisliidest, tagades sujuvad liidesed ja tõhusa andmevahetuse. [25]

3.2.4 TermSpace

TermSpace on spetsiaalselt SNOMED CT jaoks kohandatud koostööpõhine keskkond, mis toetab laienduste ja kontseptsioonide loomist, tõlkehooldust ja keele lokaliseerimist. Platvormil on palju funktsioone, millele pääseb juurde mis tahes kaasaegse brauseri kaudu, mis toimib veebipõhises raamistikus. Tähelepanuväärsed funktsioonid hõlmavad uute kontseptsioonide loomist RF2 versioonides. Platvorm toetab veebipõhise koostööd, võimaldades mitmel kasutajal samaaegselt laienduse hooldusega töötada. [26]

3.2.5 Snowstorm

Snowstorm on avatud lähtekoodiga terminoloogiaserver, mille on välja töötanud SNOMED International, et pakkuda spetsiaalset tuge SNOMED CT-le. Selle Elasticsearchi tipul ehitatud arhitektuur toetab optimaalset jõudlust. Snowstorm esitleb kahte erinevat API-d: HL7 FHIR API ja SNOMED CT API. HL7 FHIR API kaudu hõlbustab Snowstorm erinevate koodisüsteemide, sealhulgas SNOMED CT, LOINC, ICD-10 ja ICD-10-CM integreerimist ja kasutamist. SNOMED CT API on spetsiaalselt pühendatud SNOMED CT koodisüsteemi haldamisele, tegutsedes SNOMED CT brauserina ja võimaldades SNOMED CT väljaannete loomist. Rõhk avatud lähtekoodiga arhitektuuril ja Snowstormi tugevatel API-pakkumistel muudab selle väärtuslikuks varaks tervishoiuterminoloogia haldamisel. [27]

3.2.6 Hermes

Hermes hõlmab SNOMED CT-le keskendunud terminoloogiatööriistade komplekti, mis sisaldab kiiret terminoloogiateenust, millel on tugev täistekstiotsingu funktsioon. Lisaks pakub Hermes järeldusmootorit, mis suudab analüüsida SNOMED CT väljendeid ja mõisteid. Platvorm võimaldab ka ristkaardistamist, tagades sujuva tõlkimise teistesse koodisüsteemidesse ja vastupidine. Hermes toetab eelkõige SNOMED CT kompositsioonigrammatikat ja SNOMED CT väljenduspiirangute keelt. Selle mitmekülgne disain toimib raamatukoguna, mida saab integreerida suurematesse rakendustesse või kasutada iseseisvalt kui eraldiseisvat mikroteenust. [28]

3.2.7 Apelon DTS

Apelon DTS (Distributed Terminology System) on tervishoiuplatvorm, mis keskendub standardiseeritud kliiniliste terminoloogiate tõhusale haldamisele ja levitamisele. Suuremat rõhku pannes koostalitlusvõimele ja järjepidevusele, Apelon DTS pakub tsentraliseeritud hoidlat erinevate tervishoiuterminoloogiate salvestamiseks, hankimiseks ja haldamiseks. Platvormi märkimisväärsed funktsioonid hõlmavad tugevaid terminoloogiahaldusvõimalusi, dünaamiliste värskenduste versioonide loomist ja tööriistu erinevate terminoloogiate kaardistamiseks ning ristviitamiseks. Apelon DTS on integreeritud tervise infosüsteemidega, tagades elektrooniliste tervisekaartide (EHR) ja muude tervishoiurakenduste ühtse terminoloogia kasutuselevõtu. Platvorm vastab terviseandmete standarditele, toetades tunnustatud terminoloogiate, nagu SNOMED CT ja LOINC, kasutamist. [29]

3.3 Terminoloogiaserverite vastavus kriteeriumidele

Tabel 1 pakub struktureeritud ülevaadet sellest, kuidas Ontoserver, Snowray, Rhapsody, TermSpace, Snowstorm, Hermes ja Apelon DTS vastavad terminoloogiaserveri kriteeriumidele, mida on määratletud peatükis 3.1.

Tabel 1. Terminoloogiaserverite vastavus kriteeriumidele.

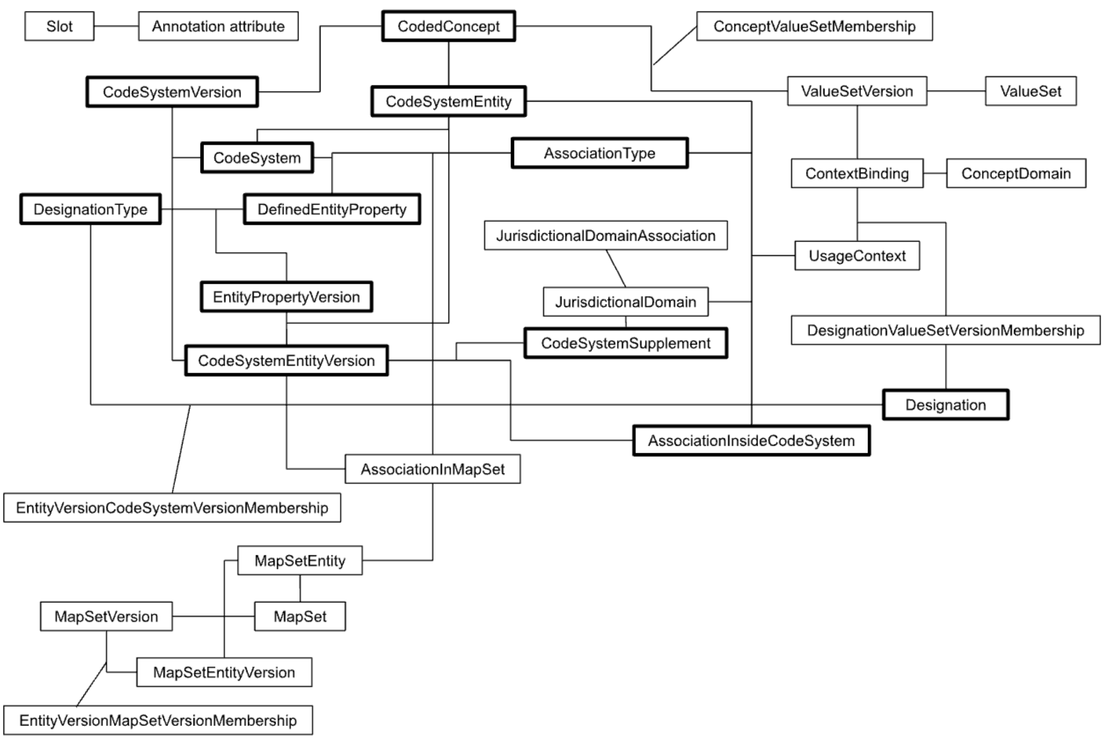
Criteria	**Onto-server**	**Snowray**	**Rhapsody**	**Term-Space**	**Snow-storm**	**Hermes**	**Apelon DTS**
Standardiseeritud terminoloogia klassifikaator	SNOMED LOINC ICD	SNOMED LOINC ICD	SNOMED LOINC ICD	SNOMED	SNOMED LOINC ICD	SNOMED	SNOMED LOINC ICD

... Tabel 1 jätkub							
Criteria	**Onto-server**	**Snowray**	**Rhapsody**	**Term-Space**	**Snow-storm**	**Hermes**	**Apelon DTS**
CRUD operatsioonid	+	+	+	+	N/A	+	N/A
Terminoloogia import	+	+	N/A	N/A	+	N/A	N/A
FHIR väljaanne	N/A	N/A	R4	N/A	R4	N/A	N/A
FHIR terminoloogiamooduli ressursid	+	+	+	N/A	+	-	+
FHIR terminoloogiamooduli operatsioonid	+	+	+	N/A	+	-	+
Sisemine andmemudel	N/A	N/A	N/A	N/A	mitte standardiseeritud andmemudel	N/A	N/A
Mitmekeelne terminoloogia	+	+	+	N/A	+	+	+
Versioneerimine	+	+	+	N/A	+	+	+
Veebi liides	+	+	+	+	-	+	+
Litsensi tüüp	C	C	C	C	F	F	C

Legend: “+” - kriteerium on vastava terminoloogiaserveri puhul täidetud; “-” - terminoloogiaserveris puudub vastav kriteerium; “N/A” - vastust sellele kriteeriumile pole saadaval; “C” - kommertslitsentsi tüüpi; “F” - vaba litsentsi tüüpi.

3.4 CTS2 kontseptuaalne mudel

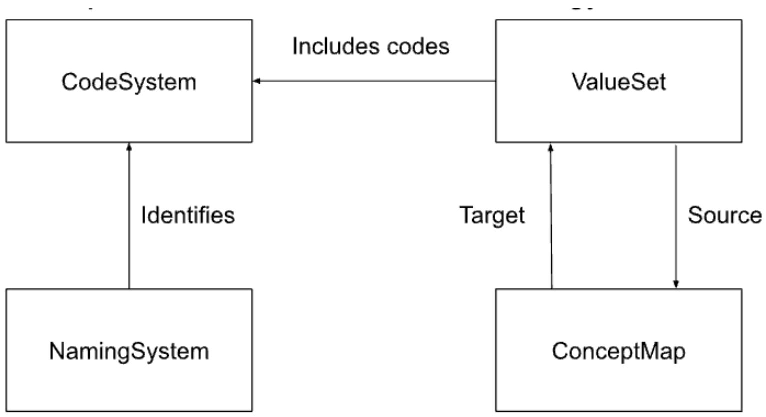
CTS2 kontseptuaalne mudel sisaldab 30 ressurssi. Joonis 1 näitab CTS2 kontseptuaalset mudelit. Rasvaste raamidega märgitud ressursid on seotud koodisüsteemiga.



Joonis 1. CTS2 kontseptuaalne mudel.

3.5 HL7 FHIR terminoloogia kontseptuaalne mudel

FHIR terminoloogia kontseptuaalne mudel sisaldab 4 ressurssi. Joonis 2 demonstreerib FHIR terminoloogiamooduli kontseptuaalset mudelit.



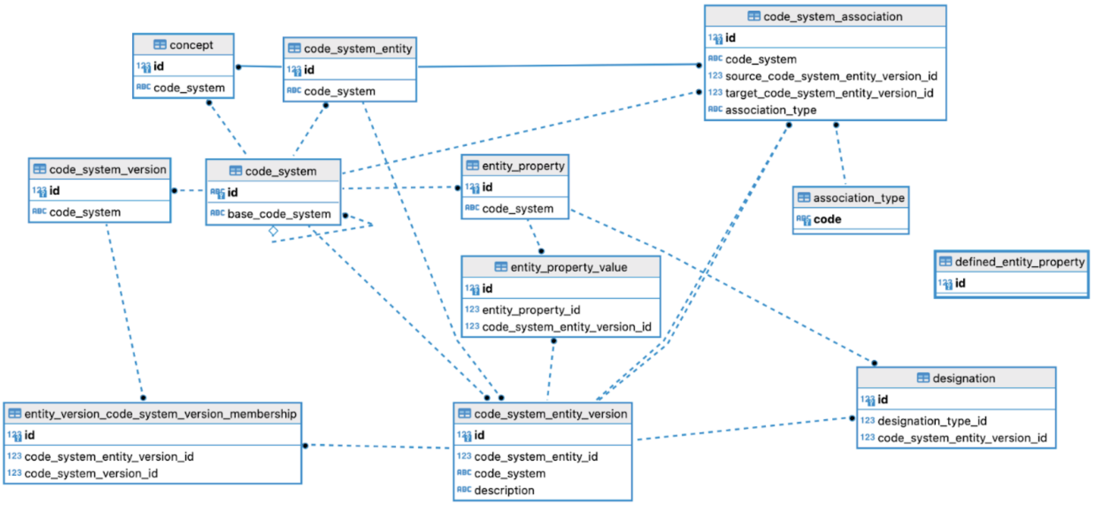
Joonis 2. FHIR terminoloogia kontseptuaalne mudel.

3.6 CTS2 ja HL7 FHIR kontseptuaalsete mudelite võrdlus

CTS2 ja FHIR kontseptuaalsete mudelite uurimisel ilmnevad erinevused, mis rõhutavad nende vastavaid tugevusi ja rakendusi. FHIR-is puudub koodisüsteemideks ja versioonideks jaotus. Erinevalt CTS2-st, kus iga versiooni käsitletakse eraldi ressursina, eksisteerib FHIR mudelis iga versioon iseseisva *CodeSystem* ressursina. Lisaks ei erista FHIR mudel *Concept* ressurssi iseseisva ressursina ja ei toeta selle versioneerimist. Seetõttu paistab CTS2 silma terviklikuma süsteemina, pakkudes tugevaid versioonimisvõimalusi. Kokkuvõtteks võib öelda, et CTS2 on terviklikum süsteem, mis sobib versioonide loomiseks ja andmete haldamiseks, kuid FHIR-i kasutatakse valmisversioonide avaldamiseks.

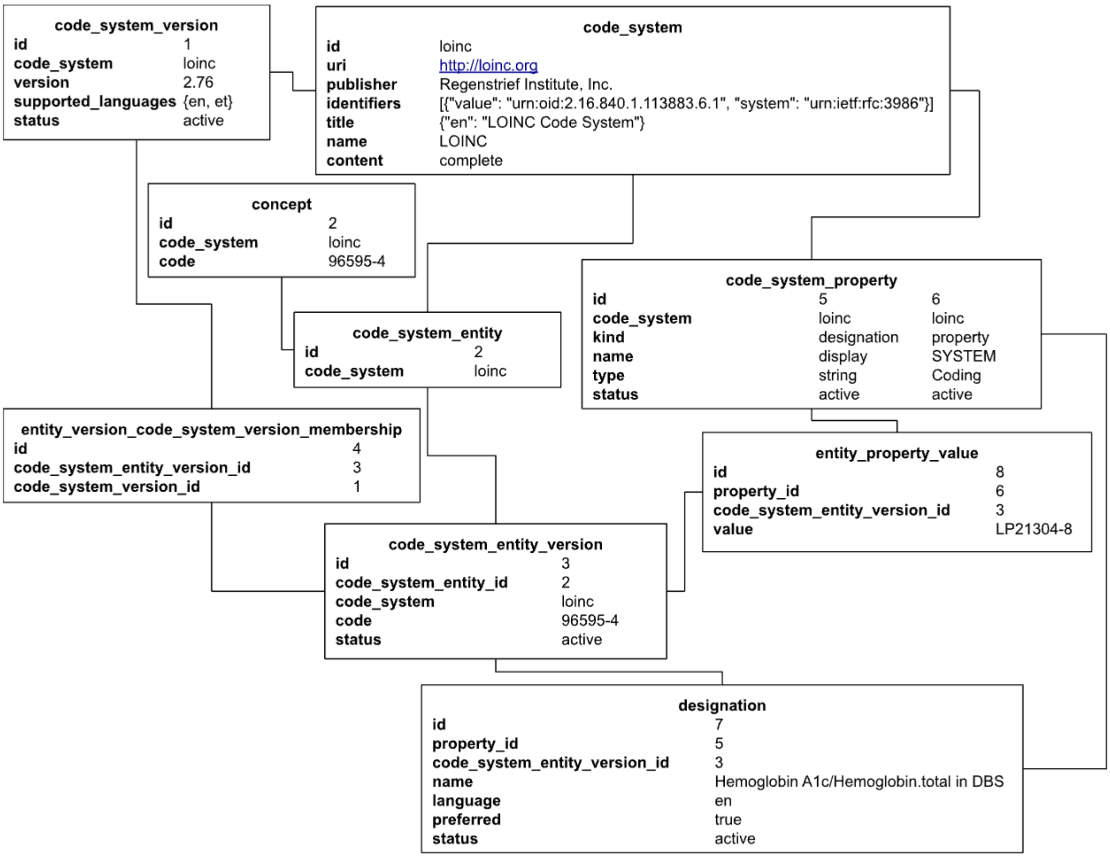
3.7 CTS2 kontseptuaalsel mudelil põhinev andmebaasi disain

Joonisel 3 kujutatud andmebaasi struktuur peegeldab relatsiooniandmebaasi koodisüsteemi ressurside kujundust, mida kohandasime CTS2 kontseptuaalsete moodulite sisemise struktuuri, seoste ja nimetustega. Kuigi meie kasutusjuhtumid ei nõudnud CTS2 kontseptsioonimudeli täielikku rakendamist, jätsime teadlikult teatud olemid välja, nagu *JurisdictionalDomain*, *UsageContext*, *ConceptDomain* jne. Vajadusel saab neid olemid lisada. Nimede selguse ja loetavuse parandamiseks tegime mõningaid muudatusi. Päringute tõhususe tagamiseks lisasime uusi veerge ja seoseid. Samuti integreerisime 19 täiendavat veergu, mis vastavad FHIR-i ressurssidele, tagamaks sujuva teisendamisprotsessi.



Joonis 3. Koodisüsteemi ressursi TermX andmebaasi disain.

Joonisel 4 on esitatud näide andmebaasiandmetest, mis põhinevad Logical Observation Identifiers, Names, and Codes (LOINC) koodisüsteemi kontseptsioonidel.



Joonis 4. LOINC-il põhinev koodisüsteemi ressursi näide.

3.8 CTS2 andmemudeli teisendamine HL7 FHIR terminoloogia ressurssidele

Esitatud on CTS2 ja FHIR kontseptuaalsete moodulite võrdlus, mille põhjal võib järeldada, et FHIR terminoloogiamoodul on CTS2-ga võrreldes primitiivsem ja võiks olla tõlgendatav CTS2 alamhulgana. Siiski tuleb märkida, et FHIR-i ressursid sisaldavad atribuute, mida CTS2-s ei leidu. Nimetatud atribuudid hõlmavad ressursi URI-d, arvuti- ja inimsõbralikke ressursi nimesid, loomise teavet (autor, toimetaja, ülevaataja, kinnitaja) ja ressursside eesmärgi kirjeldust. Andmebaasis CTS2 kontseptuaalse mooduli rakendamisel ja FHIR-i ressursside analüüsimisel oleme lisanud kõik FHIR-i spetsifikatsioonis nõutavad atribuudid. See tagab probleemivaba integreerimise FHIR-liidestega laiendatud CTS2 andmebaasimudelisse. Koodisüsteemide liideste rakendamisel on kasutusel järgmised toimingud:

- CodeSystem toimingud: GET, POST, PUT, DELETE
- HL7 FHIR terminoloogiamooduli CodeSystem operatsioonid: *lookup*, *validate-code*, *subsumes*, *find-matches*

4. Analüüs ja järeldused

Käesolevas uurimuses esitatud võrdlev analüüs kliiniliste terminoloogiaserverite kohta rõhutab mitmeid olulisi väljakutseid tervishoiuandmete vahetamisel ja koostalitlusvõime tagamisel. Metoodika, mida kasutasime nende terminoloogiaserverite hindamisel, keskendus kriitilistele kriteeriumidele, nagu standardiseeritud terminoloogia klassifikaatorite tugi, terminoloogiahaldus, vastavus FHIR terminoloogiamooduli nõuetele, veebiliides, mitmekeelse terminoloogia tugi, andmete versioneerimise võimalus ja litsentsi tüüp. See süstemaatiline hindamisprotsess võimaldas meil saada ülevaate kliinilise terminoloogiaserverite tugevustest ja nõrkustest. Ontoserver, Snowray, Rhapsody, TermSpace, Snowstorm, Hermes ja Apelon DTS pakuvad mitmekesiseid lahendusi, mis vastavad erinevatele tervishoiu informaatika vajadustele. Iga terminoloogiaserver omab ainulaadseid funktsioone ja võimalusi, mis käsitlevad kliinilise terminoloogia haldamise spetsiifilisi aspekte. Tuvastatud kriteeriumid pakuvad üksikasjalikku ülevaadet olemasolevate lahenduste tugevustest ja nõrkustest, mis annab olulise panuse kliiniliste terminoloogiaserverite valiku ja kasutamise edasisele arengule. Keskendusime järgmistele aspektidele:

- Litsentsivaba terminoloogiaserver: Arvestati ainult terminoloogiaservereid, mis järgisid vabavaralist mudelit. Sellesse kategooriasse kuulusid Snowstrom ja Hermes.
- Rikkalik andmete importimisvõimalus: Uurimisel keskenduti terminoloogiaserveritele, mis näitasid tugevat võimekust erinevate failivormingute, nagu CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC ja SNOMED RF2, edukaks importimiseks. Sellele kriteeriumile vastavad Ontoserver ja Snowray.
- Mitmekeelne veebiliides: Kõik uuritud terminoloogiaserverid vastasid mitmekeelse veebiliidese nõudele, välja arvatud TermSpace.
- Veebiredaktor ja selle mitmekeelsus: Puudus terminoloogiaserver, mis võimaldaks mitmekeelse sisu haldamist veebiliidese kaudu.
- Mitmeotstarbeline terminoloogiaserver: Võrdlusest jäeti välja Snowstorm ja TermSpace, põhjuseks nende piiratud terminoloogia tugi (põhines SNOMED CT-l).
- FHIR R5 tugi: Enamikku terminoloogiaservereid toetab FHIR R4, kuid mõnel juhul oli FHIR-versiooni toetamise teave puudu. Hermes jäeti vaatluse alt välja, kuna tal puudus uurimisperioodil FHIR-i toetus.
- Sisemine andmemudel: Andmemudeliga seotud kriteeriume ei rakendatud hindamisel, kuna vaatlusaluste terminoloogiaserverite andmemudelite kohta polnud piisavalt teavet.

Tulemuseks pole leitud meie kriteeriumidele vastavat terminoloogiaserverit. Kõik olemasolevad terminoloogiaserverid ei vasta kriteeriumitele vähemalt kahes kategoorias. Navigeerides kliinilise terminoloogiaserverite maastikul läbi meie võrdleva analüüsi, ilmnesid teatud piirangud, mis pakuvad tulevaseks arenguks selgeid suundi. Tuvastatud väljakutsed, nagu mittelitsentsivabad lahendused, vananenud järgimine standardversioonidele, piiratud suutlikkus importida väliseid ressursse levinud vormingutes (CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC ja SNOMED RF2), ühilduvus FHIR terminoloogiamooduliga ja mittestandardsete andmemudelite kasutamine, valgustavad kriitilisi valdkondi, mida praeguses ökosüsteemis parandada. Litsentsivabade lahenduste või alternatiivsete litsentsimismudelite uurimine võib soodustada kliiniliste terminoloogiaserverite laialdast kasutuselevõttu, edendades koostööd ja läbipaistvust. Samuti on oluline täiustada vastavust uusimate standardversioonide ja -väljaannetega.

Tulevased uurimistööd peaksid tagama, et kliinilised terminoloogiaserverid oleksid kursis arenevate standarditega, eriti HL7 FHIR-i puhul. Väliste ressursside importimise suutlikkuse suurendamine erinevates vormingutes, nagu CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC ja SNOMED RF2, tagab suurema paindlikkuse ja hõlpsa integreerimise, võimaldades tervishoiuorganisatsioonidel väliseid andmeallikaid sujuvalt oma terminoloogiaserveritesse lisada. Tulevased lahendused peaksid selle funktsiooni prioriteediks seadma, et parandada kasutatavust ja kohandatavust. Sisemiste andmemudelite vastavusse viimine CTS2 standarditega on tulevaste arengute põhieesmärk. Terminoloogiateenuste standardraamistiku loomine, nagu pakub CTS2, edendab koostalitlusvõimet ja järjepidevust erinevate tervishoiusüsteemide vahel. Ühtse mudeli poole liikumine võib ületada praegused lüngad ja soodustada terviklikumat lähenemisviisi kliinilise terminoloogia haldamisele. Neid väljakutseid silmas pidades oli järgmiseks töö suunaks uue, rikastatud terminoloogiaserveri lahenduse uurimine ja otsustav väljatöötamine, mis käsitleb tuvastatud piiranguid.

Oleme alustanud uudse terminoloogiaserveri loomise teekonda, milleks on TermX. TermX-i serveri ja veebiliidese lähtekood on saadaval GitLabi platvormil [30, 31]. Kuna standardiseeritud andmemudeli kasutamine oli üks nõrkematest lülidest olemasolevates terminoloogiaserverites, otsustasime keskenduda selle rakendamise kirjeldusele. Samal ajal ei piirdu TermX ainult standardiseeritud andmemudeli kasutamisega, vaid vastab kõikidele eespool nimetatud kriteeriumitele. TermX-i arendamise käigus ilmnesid väljakutsed standardiseeritud andmemudeli rakendamisel. CTS2 andmemudel valiti sisemiseks andmemudeliks ja FHIR andmemudel on kasutusel terminoloogiasüsteemide vaheliseks jagamiseks. Erinevused FHIR ja CTS2 andmemudelite vahel tekitavad väljakutseid, eriti versioonide haldamisel. Kuna FHIR käsitleb iga versiooni eraldi ressursina ja CTS2 käsitleb versiooniressursse koodisüsteemi ressursist sõltumatute üksustena, tekib küsimus versioonikoodide tõhusa teisendamise protsessi mõju kohta andmete järjepidevusele.

Märkimisväärne on arutelu CTS2 paindlikkuse üle erinevate vormingute (nt JSON-struktuuride) andmete mahutamisel. Võimalus käsitleda erinevaid keeli atribuutidel nagu pealkiri, eesmärk ja kirjeldus suurendab kasutatavust, eriti juhul, kui terminoloogiaserver teenindab laia valikut spetsialiste eri keeltes. FHIR-i poolt nõutavate atribuutide lisamine CTS2 mudelile sobivaks teisendamiseks on hädavajalik sujuva koostalitlusvõime tagamiseks kahe standardi vahel. Samuti aitab FHIR-i poolt defineeritud piirangute integreerimine terminiressursside haldusprotsessidesse kaasa terminoloogiaserveri üldise töökindluse ja töökindluse tagamisele. Andmemudeli PostgreSQL-i rakendamisel keskendusime ressursside kustutamisele, valides loogilise kustutamise, kus ressurss märgitakse kustutatuks, kuid säilitab andmed andmebaasis. See strateegia vähendab juhusliku andmekao riski ja järgib andmehalduse parimate tavade põhimõtteid. Paindlikkus ja vigade vältimine saavutatakse, võimaldades kasutajatel kustutatud koodisüsteemi koodi uuesti kasutada. Kokkuvõttes rõhutavad ülaltoodud väljakutsed ja lahendused CTS2 ja FHIR standarditele vastava terminoloogiaserveri rakendamise keerukust. Tulevased kaalutlused hõlmavad nende rakenduste täiustamist pideva tagasiside, arenevate standardite ja tekkivate nõuete kontekstis.

5. Kokkuvõte

Esimeses artiklis esitatud kliinilise terminoloogiaserverite võrdlev analüüs ja teises artiklis TermX-i väljatöötamise käigus tekkinud väljakutsete ja lahenduste uurimine aitavad ühiselt kaasa tervishoiu informaatika areneva maastiku terviklikule mõistmisele. Mõlemad artiklid rõhutavad kliinilise terminoloogiaserverite kriitilist rolli tervishoiusüsteemide koostalitlusvõime, andmete standardimise ja üldise tõhususe saavutamisel. Esimese artikli võrdlev analüüs toob esile kliinilise terminoloogiaserverite mitmekesisuse, millest igaühel on ainulaadsed omadused, mis käsitlevad terminoloogiahalduse konkreetseid aspekte. Hindamisprotsess paljastab aga olemasolevate lahenduste puhul olulisi väljakutseid ja piiranguid.

Märkimisväärne on see, et ainult mõned terminoloogiaserverid vastavad enamuse kriteeriumidele, mis rõhutab vajadust selles valdkonnas jätkuva innovatsiooni ja täiustamise järele. Tuvastatud väljakutsed, nagu mittestandardsed andmemudelid, litsentsivabad lahendused, vananenud standardversioonide järgimine, piiratud impordivõimalused ja ühilduvusprobleemid arenevate standarditega nagu FHIR, panid aluse tulevaste arengusuundade jaoks. Üleskutse standardiseeritud andmemudelite, litsentsivabade lahenduste, uusimate standardite järgimise, täiustatud impordivõimaluste ja standardiseeritud andmemudelitega vastavusse viimise järele muutub kliinilise terminoloogia haldamise valdkonna edendamise keskpunktiks.

Teine artikkel, mis keskendub TermX-i arendamisele, heidab valgust standardiseeritud andmemudelite rakendamisele. Standardiseeritud andmemudeliks oli valitud CTS2 ja andmebaas implimeteerimiseks on PostgreSQL. Arutelu hõlmab ressursside kustutamist, CTS2 andmemudeli paindlikust, erinevusi CTS2 ja FHIR vahel ja FHIR atribuutide rakendamine CTS2 andme mudelis. Need väljakutsed rõhutavad mitmetele standarditele vastava terminoloogiaserveri juurutamise keerukust ja seda, kui tähtis on nende keerukuse käsitlemine tugeva ja usaldusväärse andmehalduse jaoks. Teise artikli järeldus rõhutab TermX-i olulisust avatud lähtekoodiga terminoloogiaserverina, mis hõlmab innovatsiooni, CTS2 ja FHIR standardite järgimist ja kõikehõlmavat andmehaldust. CTS2 valik andmemudeliks, PostgreSQL andmebaasihaldusplatvormiks ja integreerimine FHIR-i ressurssidega näitavad strateegilist lähenemist koostalitlusvõime, andmete järjepidevuse ja paindlikkuse saavutamisele kliinilise terminoloogia haldamisel.

Kokkuvõtvalt võib öelda, et mõlema artikli teadmised aitavad kujundada kollektiivset visiooni kliinilise terminoloogiaserverite tulevikust. Tuvastatud väljakutsed ja nende leitud lahendused toimivad suunisena teadlastele, arendajatele ja tervishoiutöötajatele, kes soovivad edendada tervishoiu ökosüsteemi koostalitlusvõimet, järjepidevust ja tõhusust. Kuna tervishoiumaastik jätkab arenemist, peegeldab TermX-i arendamise pühendumus avatud koostööle, standarditele vastavusele ja pidevale täiustamisele ennetavat sammu sujuva, koostalitlusvõimelise ja standardiseeritud tervishoiu infrastruktuuri suunas.

Kasutatud kirjandus

[1] Moritz Lehne et al. “Why digital medicine depends on interoperability”. In: *NPJ digital medicine* 2.1 (2019), p. 79.

[2] Daniel Luna et al. “Terminology Services: Standard Terminologies to Control Medical Vocabulary. “Words are Not What they Say but What they Mean””. In: *eHealth*. Ed. by Thomas F. Heston. Rijeka: IntechOpen, 2018. Chap. 2. DOI: 10.5772/intechopen.75781. URL: https://doi.org/10.5772/intechopen.75781.

[3] HL7. *FHIR is a standard for health care data exchange, published by HL7®.* ,http://hl7.org/fhir/. 2023.

[4] HL7. *HL7 Common Terminology Services. Service Functional Model Specification. Release 2*. http://www.hl7.org/documentcenter/private/standards/CTS/V3_CTS2_r2_2015FEB_R2022.pdf. 2022.

[5] SNOMEDInternational. *SNOMED CT*. https://www.snomed.org/. 2023.

[6] Inc. Regenstrief Institute. *LOINC*. https://loinc.org/. 2023.

[7] WHO. *ICD*. https://www.who.int/. 2023.

[8] Abdullah Awaysheh et al. “A review of medical terminology standards and structured reporting”. In: *Journal of veterinary diagnostic investigation* 30.1 (2018), pp. 17–25.

[9] Duane Bender and Kamran Sartipi. “HL7 FHIR: An Agile and RESTful approach to healthcare information exchange”. In: *Proceedings of the 26th IEEE international symposium on computer-based medical systems*. IEEE. 2013, pp. 326–331.

[10] HL7. *FHIR Terminology Module*. http://hl7.org/fhir/terminology-module.html. 2023.

[11] The PostgreSQL Global Development Group. *About PostgreSQL*. https://www.postgresql.org/about. 2023.

[12] Guido Van Rossum and Fred L. Drake. *Python 3 Reference Manual*. Scotts Valley, CA: CreateSpace, 2009. ISBN: 1441412697.

[13] Ken Arnold, James Gosling, and David Holmes. *The Java programming language*. Addison Wesley Professional, 2005.

[14] David Flanagan. *JavaScript: the definitive guide*. " O’Reilly Media, Inc.", 2006.

[15] Jarosław Krochmalski. *IntelliJ IDEA essentials*. Packt Publishing Ltd, 2014.

[16] Prithwiraj Choudhury et al. “GitLab: work where you want, when you want”. In: *Journal of Organization Design* 9 (2020), pp. 1–17.

[17] Nilesh Jain, Ashok Bhansali, and Deepak Mehta. “AngularJS: A modern MVC framework in JavaScript”. In: *Journal of Global Research in Computer Science* 5.12 (2014), pp. 17–23.

[18] Sanjay Patni. “Micronaut”. In: *Pro RESTful APIs with Micronaut: Build Java-Based Microservices with REST, JSON, and XML*. Springer, 2023, pp. 17–30.

[19] Oliver Bodenreider, Ronald Cornet, and Daniel J Vreeman. “Recent developments in clinical terminologies—SNOMED CT, LOINC, and RxNorm”. In: *Yearbook of medical informatics* 27.01 (2018), pp. 129–139.

[20] Tim Benson et al. “Snomed ct”. In: *Principles of Health Interoperability: FHIR, HL7 and SNOMED CT* (2021), pp. 293–324.

[21] Jeffrey Campbell Andrews et al. *Speaking the same language: using standardized terminology*. 2016.

[22] CSIRO. *Ontoserver*. `https://ontoserver.csiro.au/`. 2023.

[23] Alejandro Metke-Jimenez et al. “Ontoserver: a syndicated terminology server”. In: *Journal of biomedical semantics* 9 (2018), pp. 1–10.

[24] B2iHealthcare. *Snowray. The Healthcare Terminology Service*. `https://snowray.app/`. 2023.

[25] Rhapsody. *Rhapsody® Semantic terminology management feature overview*. `https://rhapsody.health/resources/rhapsody-semantic-terminology-management-feature-overview/`. 2023.

[26] Termmed. *TermSpace*. `https://cf-prod-main.termspace.com/`. 2023.

[27] IHTSDO. *Snowstorm*. `https://github.com/IHTSDO/snowstorm/`. 2023.

[28] Mark Wardle. *Hermes*. `https://github.com/wardle/hermes/`. 2023.

[29] ApelonInc. *Apelon Distributed Terminology System (DTS)*. `http://www.apelondts.org/`. 2023.

[30] Kodality. *TermX. Terminology Server based on CTS2*. `https://gitlab.com/kodality/terminology/termx-server`. 2023.

[31] Kodality. *TermX web*. `https://gitlab.com/kodality/terminology/termx-web`. 2023.

Lisa 1 – Lihtlitsents lõputöö reprodutseerimiseks ja lõputöö üldsusele kättesaadavaks tegemiseks[1]

Mina, Marina Ivanova

1. Annan Tallinna Tehnikaülikoolile tasuta loa (lihtlitsentsi) enda loodud teose "Kliiniliste terminoloogiate haldamise optimeerimine: Terminoloogiaserverite analüüs, CTS2 rakendamine PostgreSQL-is ja teisendamine FHIR ressurssidele", mille juhendajad on Igor Bossenko and Gunnar Piho
   1.1. reprodutseerimiseks lõputöö säilitamise ja elektroonse avaldamise eesmärgil, sh Tallinna Tehnikaülikooli raamatukogu digikogusse lisamise eesmärgil kuni autoriõiguse kehtivuse tähtaja lõppemiseni;
   1.2. üldsusele kättesaadavaks tegemiseks Tallinna Tehnikaülikooli veebikeskkonna kaudu, sealhulgas Tallinna Tehnikaülikooli raamatukogu digikogu kaudu kuni autoriõiguse kehtivuse tähtaja lõppemiseni.
2. Olen teadlik, et käesoleva lihtlitsentsi punktis 1 nimetatud õigused jäävad alles ka autorile.
3. Kinnitan, et lihtlitsentsi andmisega ei rikuta teiste isikute intellektuaalomandi ega isikuandmete kaitse seadusest ning muudest õigusaktidest tulenevaid õigusi.

08.01.2024

[1] Lihtlitsents ei kehti juurdepääsupiirangu kehtivuse ajal vastavalt üliõpilase taotlusele lõputööle juurdepääsupiirangu kehtestamiseks, mis on allkirjastatud teaduskonna dekaani poolt, välja arvatud ülikooli õigus lõputööd reprodutseerida üksnes säilitamise eesmärgil. Kui lõputöö on loonud kaks või enam isikut oma ühise loomingulise tegevusega ning lõputöö kaas- või ühisautor(id) ei ole andnud lõputööd kaitsvale üliõpilasele kindlaksmääratud tähtajaks nõusolekut lõputöö reprodutseerimiseks ja avalikustamiseks vastavalt lihtlitsentsi punktidele 1.1. ja 1.2, siis lihtlitsents nimetatud tähtaja jooksul ei kehti.

Lisa 2 – Comparative analysis of clinical terminology servers: a quest for an improved solution

Comparative analysis of clinical terminology servers: a quest for an improved solution.

Marina Ivanova, Igor Bossenko, Gunnar Piho

December 2023

Abstract

In response to the evolving dynamics of healthcare, this research underscores the need for robust solutions to facilitate the exchange of clinical terminology, ensuring seamless communication and interoperability across healthcare systems. Terminology servers are pivotal in standardising and managing terminology, ensuring consistent communication and knowledge sharing. We must choose a modern, highly customisable, multilingual terminology server that supports FHIR and standard terminologies. This article offers a comprehensive overview of the challenges and limitations of existing clinical terminology exchange methods. We evaluate the strengths and weaknesses of prominent terminology servers. The findings reveal crucial insights into the current landscape of terminology management solutions, uncovering limitations and potential gaps. As a result, the article concludes with a compelling argument for the need to explore and develop a new enhanced terminology server solution. This exploration responds to the evolving demands of the modern healthcare industry and sets the stage for future advancements in clinical terminology management.

Keywords: Clinical Terminology Exchange, Terminology Server, Clinical Terminology Management, HL7 Fast Healthcare Interoperability Resources (FHIR), Common Terminology Services 2 (CTS2)

1 Introduction

In the era of digital healthcare, the effective exchange and management of clinical information are critical for enhancing patient care, research, and overall healthcare outcomes. Digitalising healthcare processes has led to diverse medical terminologies and data structures. Achieving seamless interoperability among disparate systems requires a common language for expressing clinical concepts. The success of digital medicine is contingent upon interoperability, emphasising the need for standardised clinical terminologies to bridge communication gaps between healthcare systems. Clinical terminology servers play a pivotal role in this landscape by providing a standardised framework for medical vocabulary, facilitating interoperability, and ensuring accurate data representation [1].

1.1 Standards in Healthcare Data Exchange

The healthcare industry's pursuit of interoperability has led to the development of healthcare data exchange standards. These standards are used every day by healthcare industry workers for record documentation, illness descriptions, etc.

HL7 Fast Healthcare Interoperability Resources (FHIR) is a modern healthcare data exchange cornerstone [2]. HL7 FHIR adopts an agile and RESTful approach, providing a flexible and efficient mechanism for sharing healthcare information over the web. Its standards-based approach promotes a common language for healthcare entities. The evolution of HL7 FHIR through its releases, including the latest R5, contributes to the adaptability and resilience of the framework, aligning it with the evolving landscape of healthcare technology [3]. The adoption of HL7 FHIR has been instrumental in addressing the challenges regarding the dependence of digital medicine on interoperability, particularly within the realm of clinical terminology [1, 3].

Common Terminology Services 2 (CTS2) aims to establish a standardised interface for utilising and managing terminologies within health information technology by providing the core capabilities, functionalities, and conceptual models [4]. CTS2 connects to HL7 FHIR by providing a standardised set of models, services, and interfaces for managing and accessing terminologies [5].

1.2 HL7 FHIR Terminology Module

The HL7 FHIR (Fast Healthcare Interoperability Resources) Terminology Module is a crucial component within the HL7 FHIR standard, focused on standardising and managing the terminologies, codes, and concepts used in healthcare information exchange [6].

HL7 FHIR Terminology Module Resources:

- *CodeSystem* describes a set of codes with their meanings and relationships, specifies the rules for creating and interpreting codes within a particular domain, and includes metadata such as version information and the authority responsible for the code system [6].

- *ValueSet* defines a set of codes drawn from one or more code systems. Specifies the concepts or codes that can be used for a particular purpose, such as describing a clinical condition or a type of observation [6].

- *ConceptMap* facilitates the mapping of codes and concepts between different code systems, enables translation of data between systems that use different terminologies, and helps ensure consistency and accuracy when exchanging healthcare information [6].

HL7 FHIR Terminology Module Operations:

- *validate-code* checks whether a given code is valid within a specified ValueSet or CodeSystem and ensures that the codes used in HL7 FHIR resources adhere to the defined standards [6].

- *expand* retrieves the detailed list of codes included in a ValueSet, considering any hierarchical relationships or dependencies. It helps understand the complete set of codes associated with a particular concept [6].

- *lookup* provides additional information about a specific code, such as its display name, definition, and properties, and enhances the understanding of the meaning and context of a code [6].

- *translate* translates codes and concepts between different code systems using a specified ConceptMap, ensuring interoperability by facilitating information exchange across systems with varying terminologies [6].

HL7 FHIR includes a resource called "*CapabilityStatement*" that details the features and capabilities a FHIR server supports, including its interactions, search parameters, documentation, and the specific FHIR profiles and resources supported [6].

1.3 Standardised Terminology Classifications

The healthcare industry relies on a variety of standardised classifications. Standardised Terminology Classifications (STCs) form the backbone of effective communication, interoperability, and precision in exchanging clinical information. These classifications are standardised terms and codes used to represent medical concepts [7].

Standardised terminologies enhance communication, ensure data consistency, and support structured reporting within healthcare systems [7, 2]. Adopting data exchange standards and standardised terminologies such as SNOMED CT [8], LOINC [9], and ICD [10] allows the ability to speak the same language in healthcare to facilitate seamless communication and data exchange.

1.4 Terminology Server

A Terminology Server (TS) in the context of medical terminology is a specialised software application designed to facilitate the creation, organisation, and exchange of standardised clinical vocabularies within the healthcare domain [11]. A TS is a centralised repository for storing and managing medical terminologies. It provides a structured environment where healthcare professionals, researchers, and system developers can access, update, and contribute to standardised clinical terms.

2 Problem

In developing a new health information system, we faced the need to use and develop terminology following the FHIR standard. The list of requirements included support for standardised terminologies, multilingual terminologies, data import/export, versioning, authoring, integration with other terminology servers and authentication systems, etc. We described the detailed criteria for comparing terminology servers in the "Terminology server criteria" section. This article addresses whether a terminology server meeting our specified requirements exists and answers the question of the strengths and weaknesses of existing terminology servers.

3 Methodology

The methodology employed for this study is rooted in a comprehensive investigation and selection process of criteria that delineate an effective clinical terminology server. This initial phase aimed to establish a robust foundation for the subsequent comparison of servers. We meticulously curated the requirements to encapsulate essential aspects such as multilingual support, versioning mechanisms, adherence to standards, semantic accuracy, interoperability, usability, clinical relevance, and cross-domain integration.

With this well-defined set of criteria, our study focused on acquiring a nuanced understanding of the current landscape of clinical terminology servers through a structured approach. This approach encompassed various stages, including data collection, identification of commonly used servers, brief reviews of each server, and a subsequent comprehensive comparison.

We extensively reviewed existing literature and resources to gather insights into the current state of clinical terminology servers, using search words like *clinical terminology* and *clinical terminology server*, *clinical terminology standard*, *medical terminology server*, and *FHIR terminology*. This review involved the analysis of studies, articles, and reports relevant to the utilisation and challenges associated with clinical terminology servers in contemporary healthcare settings. Additionally, we consulted healthcare professionals, delved into industry standards, and considered the prevalence of these servers in current healthcare practices.

A systematic and thorough comparison of the selected clinical terminology servers was subsequently conducted based on the predefined criteria. This approach ensures a comprehensive and rigorous assessment, providing valuable insights into the diverse landscape of clinical terminology servers and their alignment with the established criteria.

4 Results

4.1 Terminology server criteria

Essential criteria for evaluating a clinical terminology server should encompass various aspects to ensure effectiveness and suitability for healthcare settings. We selected the following criteria for the comparison of terminology servers:

- **Standardised terminology classification support**

  A crucial criterion for evaluating clinical terminology servers is their support for standardised classification systems such as SNOMED CT and LOINC. These standards ensure consistency and interoperability in the representation of medical concepts [12, 13].

- **Terminology management: CRUD operations**

  Effective terminology (CodeSystem, Concept, ValueSet, ConceptMap) management is assessed by implementing CRUD (Create, Read, Update, Delete) operations. This criterion ensures that the terminology server allows seamless manipulation of medical terms, reflecting changes and updates in clinical knowledge [1, 11].

- **Terminology import**

  The ability to import terminologies from formats like CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC, and SNOMED RF2 is a practical criterion for enhancing usability and facilitating the integration of external data sources into the terminology server [14].

- **HL7 FHIR terminology module resources and operations**

  Support for HL7 FHIR terminology module resources is essential for aligning with modern interoperability standards. These resources enable the exchange of standardised healthcare information. Evaluation of terminology module operations in HL7 FHIR ensures that the terminology server aligns with the agile and RESTful approach to healthcare information exchange per HL7 FHIR standards [2].

- **Internal data model**

  The internal data model is a fundamental criterion for clinical terminology servers because it underpins the interoperability, consistency, semantic clarity, and adaptability to standards necessary for effective and efficient healthcare information exchange within a broader ecosystem. Based on widely accepted standards like CTS2 or ontology, a standardised internal data model facilitates semantic interoperability by providing a common semantic foundation for representing clinical concepts [4].

- **Versioning**

  Versioning mechanisms are critical for tracking changes in clinical terminologies over time. Versioning ensures data consistency and provides a historical perspective on the evolution of medical standards [1].

- **Multilingual terminology**

  Multilingual terminology support is essential for catering to diverse patient populations and promoting global interoperability. It ensures that terminology definitions and medical concepts can be accurately represented in multiple languages [1, 11].

- **Web interface**

  The accessibility and user-friendliness of clinical terminology servers are paramount in today's digital healthcare environment. A user-friendly multilingual web interface enhances the ease with which healthcare professionals interact with and navigate the terminology system. Evaluating the web interface ensures that the clinical terminology server aligns with modern usability standards, fostering efficient utilisation by healthcare practitioners [14].

- **License type**

  The selection of a license type, whether commercial or open-source, constitutes a pivotal criterion that significantly influences the adoption and sustainability of a clinical terminology server. Open-source solutions promote collaboration, transparency, and community-driven development, potentially leading to widespread adoption. Conversely, commercial products may offer additional features, support, and services. Evaluating the license type is crucial in understanding the terminology server's cost, flexibility, and long-term viability within the healthcare ecosystem [11].

4.2 Overview of existing terminology servers

Within the dynamic landscape of healthcare informatics, diverse clinical terminology servers offer unique features and capabilities, each contributing to the ever-evolving ecosystem.

- **Ontoserver**

  Ontoserver is a syndicated terminology server designed to facilitate the efficient management and dissemination of biomedical terminologies. The primary goal of Ontoserver is to provide a centralised platform for the storage, retrieval, and distribution of biomedical terminologies, enabling standardised communication and interoperability in the healthcare and biomedical research domains. Critical features of Ontoserver include its ability to syndicate terminologies in a standardised manner, ensuring consistency and accuracy across different instances. The syndication model also supports the dynamic updating of terminologies, ensuring users can access the most current and relevant information. [15, 16]

- **Snowray**

  Snowray represents a web-based solution that effectively manages high-quality terminology content. Its primary purpose is to assist medical terminologists in seamlessly creating and administrating resources. Users can generate new resources or import existing ones into the platform. Within Snowray, users can effortlessly expand and maintain resources, benefiting from its user-friendly interface and useful functionalities. Besides accessing international standards, Snowray provides functionality for constructing and designing Code Systems, Value Sets, and Concept Maps from the ground up. Users can efficiently manage feedback, request changes, or engage in discussions by utilising Snowray's built-in issue system, enabling the creation of specific resource-related issues. [17]

- **Rhapsody**

  Rhapsody Semantic provides a comprehensive suite of tools for achieving semantic interoperability through effective terminology management. It can seamlessly integrate into your current applications or operate independently as a standalone solution. Rhapsody features a content and subset library, auto-mapping capabilities, and a universal browsing interface, facilitating smooth interfaces and data exchange. [18]

- **TermSpace**

  TermSpace is a collaborative authoring environment tailored explicitly for SNOMED CT, facilitating the seamless editing of extensions, concept creation, translation maintenance, and language localisation. The platform boasts many features accessible through any modern browser, operating within a web-based framework and offering users an efficient, low-overhead solution. Noteworthy functionalities include the creation of new concepts in real-time and batch Quality Assurance (QA) and RF2 releases. The platform supports collaborative online efforts, allowing multiple users to work concurrently on extension maintenance. [19]

- **Snowstorm**

  Snowstorm is an open-source terminology server developed by SNOMED International and designed to offer specialised support for SNOMED CT. Constructed atop Elasticsearch, its architecture prioritises optimal performance and enterprise-level scalability. Snowstorm presents two distinct APIs: the HL7 FHIR API and the Specialist SNOMED CT API. Through the HL7 FHIR API, Snowstorm facilitates integrating and utilising various code systems, including SNOMED CT, LOINC, ICD-10, and ICD-10-CM, among others. The Specialist SNOMED CT API is dedicated to managing the SNOMED CT code system, serving as a SNOMED CT Browser, and enabling the authoring of SNOMED CT editions. The emphasis on open-source architecture and Snowstorm's robust API offerings position it as a valuable asset in healthcare terminology management. [20]

- **Hermes**

  Hermes encompasses a suite of terminology tools centred around SNOMED CT, featuring a high-speed terminology service equipped with robust full-text search functionality. This service is particularly well-suited for driving auto-completion in user interfaces. Additionally, Hermes incorporates an inference engine capable of analysing SNOMED

CT expressions and concepts, facilitating the extraction of meaningful insights. The platform also offers cross-mapping capabilities, allowing seamless translation to and from other code systems. Hermes notably supports SNOMED CT compositional grammar and the SNOMED CT expression constraint language. Its versatile design functions as a library for integration into larger applications and as an independent, standalone microservice. [21]

- **Apelon DTS**

  Apelon DTS (Distributed Terminology System) is a pivotal healthcare platform dedicated to meticulously managing and disseminating standardised clinical terminologies and associated value sets. With a primary focus on promoting interoperability and consistency, Apelon DTS offers a centralised repository for storing, retrieving, and administering diverse healthcare terminologies. This system addresses the critical need for a common framework facilitating seamless communication and data exchange across various healthcare applications. Noteworthy features include robust terminology management capabilities, versioning support for dynamic updates, and tools for mapping and cross-referencing between disparate terminologies. Apelon DTS integrates with health information systems, ensuring the uniform adoption of terminologies in electronic health records (EHRs) and other healthcare applications. The system safeguards sensitive healthcare information. Compliant with healthcare data standards, Apelon DTS upholds the use of established terminologies such as SNOMED CT and LOINC. As an evolving solution, Apelon DTS continues to play a crucial role in enhancing the efficiency and consistency of healthcare data management. [22]

4.3 Terminology server comparison

The Table 1 provides a structured overview of how Ontoserver, Snowray, Rhapsody, TermSpace, Snowstorm, Hermes, and Apelon DTS encompass terminology server criteria such as standardised terminology classification support, terminology management capabilities, HL7 FHIR integration, multilingual terminology support, versioning mechanisms, web interface usability, and license type. This comparative analysis serves as a valuable resource for healthcare professionals, system developers, and researchers seeking an informed understanding of the strengths and weaknesses of each clinical terminology server. The insights derived from this comparison aim to guide decision-making processes and contribute to the ongoing quest for an improved solution in the dynamic landscape of clinical terminology management.

Table 1: Terminology server compliance with criteria

Criteria	Onto-server	Snowray	Rhapsody	Term-Space	Snow-storm	Hermes	Apelon DTS
Standardised terminology classification	SNOMED LOINC ICD	SNOMED LOINC ICD	SNOMED LOINC ICD	SNOMED	SNOMED LOINC ICD	SNOMED	SNOMED LOINC ICD
CRUD operations	+	+	+	+	N/A	+	N/A
Code System import	+	+	N/A	N/A	+	N/A	N/A
Supported FHIR release	N/A	N/A	R4	N/A	R4	N/A	N/A
FHIR terminology module resources	+	+	+	N/A	+	-	+
FHIR terminology module operations	+	+	+	N/A	+	-	+
Internal data model	N/A	N/A	N/A	N/A	own data model	N/A	N/A
Multilingual terminology	+	+	+	N/A	+	+	+
Versioning	+	+	+	N/A	+	+	+
Web interface	+	+	+	+	-	+	+
License type	C	C	C	C	F	F	C

Legend: + means criterion is present in the Terminology Server; - means criterion is not present in the Terminology Server; N/A means no answer available for this criteria; C means commercial license type; F means free license type.

5 Discussion

The comparative analysis of clinical terminology servers presented in this article highlights several key considerations and challenges in healthcare data exchange and interoperability. The methodology employed in evaluating these servers centred around essential criteria, such as standardised terminology classification support, terminology management, compliance with the FHIR Terminology module requirements, web user interface, multilingual terminology support, versioning mechanisms, and license type. Through this rigorous evaluation, we gained valuable insights into the strengths and weaknesses of prominent clinical terminology servers, paving the way for a nuanced discussion on their implications for the healthcare industry.

Exploring existing terminology servers, including Ontoserver, Snowray, Rhapsody, TermSpace, Snowstorm, Hermes, and Apelon DTS, reveals diverse solutions catering to different needs within the healthcare informatics landscape. Each server has unique features and capabilities, addressing specific aspects of clinical terminology management. The identified criteria provide a holistic view of the strengths and weaknesses of existing solutions, guiding future developments in the quest for an improved terminology server.

During the evaluation process, we employed specific criteria to assess the capabilities of various servers. The examination focused on the following aspects:

- *Licence-free server*: Only servers adhering to the "free" model were considered. Snowstorm and Hermes were included in this category.

- *Rich Import Ability*: Servers demonstrating robust import ability for various file formats, including CSV, TSV, FHIR JSON, FSH, ClaML

XML, LOINC, and SNOMED RF2 files, were sought. Ontoserver and Snowray were identified as matching this criterion.

- *Multilingual Web Interface*: All servers evaluated met the requirement of a multilingual web interface, except for TermSpace.

- *Web Editor and Multilingual Content Editing*: Unfortunately, no server was identified that allowed the editing of multilingual content through a web interface.

- *Multipurpose Server*: The evaluation excluded Snowstorm and TermSpace due to its limited support for terminologies, except for SNOMED CT.

- *FHIR R5 Support*: While most servers exhibited support for FHIR R4, they were only found to have support for FHIR R5. Hermes was excluded from consideration due to its lack of FHIR support during the research period.

- *Well-Known Data Model*: The assessment did not apply the criteria related to a well-known data model, as sufficient information about the data models of the servers under consideration was unavailable.

As a result, we don't find a terminology server that matches our criteria. All existing servers fail in at least two categories.

5.1 Further work

As we navigate the intricate landscape of clinical terminology servers through the lens of our comparative analysis, certain limitations have emerged, offering distinct directions for future development. The identified challenges, including non-license-free solutions, outdated adherence to standard versions, limited capacity for importing external resources in common formats like CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC, and SNOMED RF2, compatibility with FHIR Terminology Module, and use of non-standard data models illuminate critical areas for improvement within the current ecosystem.

Exploring the feasibility of developing license-free solutions or alternative licensing models can contribute to the widespread adoption of clinical terminology servers, fostering collaboration, transparency, and community-driven development.

The imperative to align with the latest standard versions and releases represents a critical area for improvement. Future research efforts should ensure clinical terminology servers stay abreast of evolving standards, particularly in HL7 FHIR.

Enhancing the capacity for importing external resources in widely used formats such as CSV, TSV, FHIR JSON, FSH, ClaML XML, LOINC, and SNOMED RF2 is paramount. This capability ensures greater flexibility and ease of integration, allowing healthcare organisations to seamlessly incorporate external data sources into their terminology servers. Future solutions should prioritise this functionality to enhance usability and adaptability.

Aligning internal data models with the CTS2 standards is a fundamental goal for future developments. Establishing a standardised framework for terminology services, as provided by CTS2, promotes interoperability and consistency across different healthcare systems. Moving towards a unified model can bridge the current gaps and foster a more integrated approach to clinical terminology management.

In light of these challenges, a significant direction for future work involves investigating and decisively developing a new, enriched terminology server solution that addresses the identified limitations. We have decided to embark on the journey of creating a novel clinical terminology server rooted in the principles of open collaboration, adherence to the latest standards, and enhanced import capabilities. By actively addressing these areas for improvement and taking concrete steps toward creating a new solution that enriches the current landscape, we can collectively contribute to the evolution of clinical terminology management. This forward-looking approach ensures that our tools meet current needs and adapt to the evolving demands of modern healthcare, fostering a more seamless, interoperable, and standardised healthcare ecosystem.

In addition to outlining the vision and direction for developing a novel clinical terminology server, we introduce TermX—an [23] open-source solution designed to revolutionise clinical terminology management. TermX embodies our commitment to open collaboration, adherence to the latest standards, and enhanced import capabilities. For those eager to delve deeper into the intricacies of TermX and explore its functionalities, we will publish a series of articles offering comprehensive insights into its architecture and features. The source code for TermX is readily available on the GitLab platform [24, 25], providing transparency and inviting contributions from the wider community.

6 Conclusion

The comparative analysis of clinical terminology servers presented in this research underscores the pivotal role these servers play in the evolving landscape of healthcare informatics. The diverse functionalities of these clinical terminology servers cater to distinct needs within the healthcare ecosystem, offering a range of features from efficient terminology syndication to collaborative authoring environments. The comparison table is a practical resource for healthcare professionals, system developers, and researchers seeking informed guidance in selecting an appropriate clinical terminology server.

However, the analysis also revealed areas for improvement in the existing ecosystem. In the quest for an improved solution, future work should ensure adherence to the latest standards, enhance import capabilities for flexibility, support FHIR, multilingual web viewer and editor, support multilingual content, and align internal data models with widely accepted standards. By actively addressing these areas, the healthcare industry can foster collaboration, transparency, and community-driven development, ultimately contributing to a more seamless, interoperable, standardised healthcare ecosystem.

As the healthcare landscape evolves, the insights derived from this comparative analysis inform and decisively propel our decision-making processes toward developing future clinical terminology servers. We created a new, flexible, forward-looking, open-source terminology server in response to our needs and challenges. This strategic initiative aims to lead us collectively toward a more efficient, consistent, and adaptable healthcare informatics infrastructure.

Authors' contribution

M.I. wrote the manuscript with support from I.B. All authors contributed to the final version. I.B. and G.P. supervised the project.

References

[1] M. Lehne, J. Sass, A. Essenwanger, J. Schepers, and S. Thun, "Why digital medicine depends on interoperability," *NPJ digital medicine*, vol. 2, no. 1, p. 79, 2019.

[2] D. Bender and K. Sartipi, "Hl7 fhir: An agile and restful approach to healthcare information exchange," in *Proceedings of the 26th IEEE international symposium on computer-based medical systems*, pp. 326–331, IEEE, 2013.

[3] HL7, "Fhir is a standard for health care data exchange, published by hl7®.." ,`http://hl7.org/fhir/`, 2023.

[4] HL7, "Hl7 common terminology services. service functional model specification. release 2." `http://www.hl7.org/documentcenter/private/standards/CTS/V3_CTS2_r2_2015FEB_R2022.pdf`, 2022.

[5] R. Gazzarata, N. Maggi, L. D. Magnoni, M. E. Monteverde, C. Ruggiero, and M. Giacomini, "Semantics management for a regional health information system in italy by cts2 and fhir," in *Applying the FAIR Principles to Accelerate Health Research in Europe in the Post COVID-19 Era: Proceedings of the 2021 EFMI Special Topic Conference*, vol. 287, p. 119, IOS Press, 2021.

[6] HL7, "Fhir terminology module." `http://hl7.org/fhir/terminology-module.html`, 2023.

[7] A. Awaysheh, J. Wilcke, F. Elvinger, L. Rees, W. Fan, and K. Zimmerman, "A review of medical terminology standards and structured reporting," *Journal of veterinary diagnostic investigation*, vol. 30, no. 1, pp. 17–25, 2018.

[8] SNOMEDInternational, "Snomed ct." `https://www.snomed.org/`, 2023.

[9] I. Regenstrief Institute, "Loinc." https://loinc.org/, 2023.

[10] WHO, "Icd." https://www.who.int/, 2023.

[11] D. Luna, C. Otero, M. L. Gambarte, and J. Frangella, "Terminology services: Standard terminologies to control medical vocabulary. "words are not what they say but what they mean"," in *eHealth* (T. F. Heston, ed.), ch. 2, Rijeka: IntechOpen, 2018.

[12] O. Bodenreider, R. Cornet, and D. J. Vreeman, "Recent developments in clinical terminologies—snomed ct, loinc, and rxnorm," *Yearbook of medical informatics*, vol. 27, no. 01, pp. 129–139, 2018.

[13] T. Benson, G. Grieve, T. Benson, and G. Grieve, "Snomed ct," *Principles of Health Interoperability: FHIR, HL7 and SNOMED CT*, pp. 293–324, 2021.

[14] J. C. Andrews, F. Bogliatto, H. W. Lawson, and J. Bornstein, "Speaking the same language: using standardized terminology," 2016.

[15] A. Metke-Jimenez, J. Steel, D. Hansen, and M. Lawley, "Ontoserver: a syndicated terminology server," *Journal of biomedical semantics*, vol. 9, pp. 1–10, 2018.

[16] CSIRO, "Ontoserver." https://ontoserver.csiro.au/, 2023.

[17] B2iHealthcare, "Snowray. the healthcare terminology service." https://snowray.app/, 2023.

[18] Rhapsody, "Rhapsody® semantic terminology management feature overview." https://rhapsody.health/resources/rhapsody-semantic-terminology-management-feature-overview/, 2023.

[19] Termmed, "Termspace." https://cf-prod-main.termspace.com/, 2023.

[20] IHTSDO, "Snowstorm." https://github.com/IHTSDO/snowstorm/, 2023.

[21] M. Wardle, "Hermes." https://github.com/wardle/hermes/, 2023.

[22] ApelonInc., "Apelon distributed terminology system (dts)." http://www.apelondts.org/, 2023.

[23] Kodality, "Termx tutorial." https://termx.kodality.dev/wiki/termx-tutorial/about, 2023.

[24] Kodality, "Termx. terminology server based on cts2." https://gitlab.com/kodality/terminology/termx-server, 2023.

[25] Kodality, "Termx web." https://gitlab.com/kodality/terminology/termx-web, 2023.

Lisa 3 – TermX - Bridging the Gap: Implementing CTS2 and FHIR compatible Terminology Server

TermX - Bridging the Gap: Implementing CTS2 and FHIR compatible Terminology Server.

Marina Ivanova, Igor Bossenko, Gunnar Piho

December 2023

Abstract

As healthcare systems evolve, achieving interoperability and seamless data exchange becomes paramount. The key component of the data exchange is terminology managed by the terminology server. During "*Comparative Analysis of Clinical Terminology Servers: A Quest for an Improved Solution.*" research, we didn't find a terminology server suitable for our criteria and decided to develop our own terminology server. This article delves into implementing the Common Terminology Services 2 (CTS2) standard on PostgreSQL, a robust open-source relational database. The discussion encompasses the intricacies of integrating CTS2 with PostgreSQL, exploring the challenges and solutions encountered during the process. Additionally, the article comprehensively maps this implementation to HL7 Fast Healthcare Interoperability Resources (FHIR), a widely adopted standard for healthcare data exchange. Readers will gain insights into the technical aspects of the implementation, practical considerations, and the potential impact on healthcare data management. This exploration aims to guide developers, healthcare IT professionals, and stakeholders in leveraging CTS2 on PostgreSQL while ensuring compatibility with HL7 FHIR resources, ultimately fostering improved interoperability in the dynamic landscape of healthcare data systems.

Keywords: TermX, terminology server, PostgreSQL, CTS2, HL7 FHIR, healthcare interoperability, clinical data exchange

1 Introduction

In the dynamic healthcare landscape, combining technological innovation and robust clinical terminology management is a cornerstone for achieving comprehensive interoperability and data standardization [1]. The healthcare sector is undergoing a paradigm shift driven by the imperative recognition of the pivotal role played by clinical terminologies, encompassing Code Systems, ValueSets, and ConceptMaps. Unified and standardized internal data models are essential for achieving interoperability transcending the complexities of storing, retrieving, and exchanging clinical information [paper1]. This research covers the design of the code system and its subcomponents.

1.1 Rationale for CTS2 Implementation

Common Terminology Services 2 (CTS2) is a standard that defines different code systems, value sets, and map sets, focusing on terminology services, including terminology mapping, versioning, and access. CTS2 was developed by HL7 in 2015 and revised in 2022. CTS published as "Service Functional Model Specification" for HL7 Common Terminology Services [2].

Choosing CTS2 as a data model can benefit certain contexts, particularly in domains where standardized representation and management of terminologies are essential [3, 4]. Here are some reasons why CTS2 might be chosen as a data model:

- **Standardization**: CTS2 is a standard developed in the cooperation of the Object Management Group (OMG)[5] and Health Level 7 (HL7). Choosing CTS2 as a data model ensures adherence to a widely recognized and accepted standard for representing terminologies. Standardization can promote consistency and interoperability across different systems and applications. [6]

- **Interoperability**: CTS2 design supports interoperability by providing a common framework for representing and accessing terminological content. Choosing CTS2 can facilitate seamless integration and data exchange between healthcare systems and applications that need to work with terminologies. [6, 4]

- **Flexibility**: CTS2 design is flexible and accommodates various terminologies and code systems. This flexibility is valuable when different organizations or systems use different terminologies and a unified approach is needed to integrate and manage them.

- **Mapping and Cross-Referencing**: CTS2 supports mapping and cross-referencing of concepts across different terminologies. If your data model requires the ability to link or translate between different coding schemes, CTS2 provides mechanisms for achieving this. [6]

- **Versioning**: CTS2 supports versioning of terminologies, allowing for tracking changes over time. Versioning is crucial when terminologies are regularly updated or revised, ensuring data remains accurate and aligned with the latest standards. [6]

- **Community Adoption**: If your organization is part of a community or industry that has widely adopted CTS2, choosing it as a data model can facilitate collaboration and interoperability with other stakeholders in the same domain. [5]

- **Integration with Health Information Systems**: CTS2 design integrates with health information systems. If your data model needs to align with healthcare standards and terminology requirements, CTS2 can be a suitable choice. [4]

1.2 PostgreSQL as the Database Management Platform

Choosing a reliable database management system is paramount in healthcare settings, where data integrity, security, and accessibility are critical factors. PostgreSQL as a relational database management system (RDBMS) is a compelling option for healthcare institutions seeking a stable and scalable solution for managing clinical terminology. [7, 8] The key features and reasons for choosing PostgreSQL:

- **Open Source**: PostgreSQL is released under the PostgreSQL License, which allows for free use, modification, and distribution of the software.
- **Indexing Options**: PostgreSQL provides various indexing methods, including B-tree, Hash, GiST (Generalized Search Tree), GIN (Generalized Inverted Index), and SP-GiST (Space-Partitioned Generalized Search Tree). These indexing options contribute to efficient data retrieval.
- **Complex Queries**: PostgreSQL supports complex queries, including JOINs and subqueries, allowing the retrieval and analysis of data flexibly and powerfully.
- **Full Text Search**: PostgreSQL provides powerful full-text search capabilities, including support for various languages and search operators.
- **JSON and JSONB Support**: JSONB in PostgreSQL is a powerful feature that facilitates the storage, indexing, querying, and manipulation of JSON data within the relational database, offering a balance between flexibility and performance. JSONB allows flexibility. It does not enforce strict data integrity constraints typically found in relational databases. However, PostgreSQL provides mechanisms to validate JSON data through constraints or triggers if required.

1.3 TermX

TermX is a unique open-source platform for terminology and knowledge management. The main goals of developing TermX were adhering to the latest standards, enhancing import capabilities for unmatched flexibility, supporting FHIR, and introducing a multilingual web viewer and editor. TermX also champions the cause of multilingual content, recognizing the importance of linguistic diversity. Furthermore, internal data models are meticulously aligned with widely accepted standards, like CTS2, to ensure seamless integration and compatibility.

1.4 FHIR terminology module

The FHIR Terminology Model defines how codes and terminologies are used within the FHIR specification [2]. The HL7 FHIR terminology module provides a common language for terminology representation. By adopting FHIR resources, organizations can overcome the heterogeneity of internal data models and establish a uniform framework for information exchange. This module includes a comprehensive set of resources, such as CodeSystem, ValueSet, and ConceptMap, which facilitate semantic interoperability and data consistency. Transforming internal data models to FHIR resources promotes semantic consistency across healthcare systems. This consistency ensures that data elements are interpreted uniformly. While adopting FHIR terminology modules offers significant benefits, the transformation process has challenges in data mapping complexity, resource versioning, updates, and customization [9].

1.5 Building blocks of the terminology module

A **concept** is a unique and distinct idea or entity within the realm of health and medicine that can be precisely defined and represented. Concepts in clinical terminology are often abstract and cover a wide range of topics, including diseases, symptoms, procedures, medications, observations, and other healthcare-related elements. Figure 1 represents necessary information about the use of concept entities like code, properties, designations, and associations.

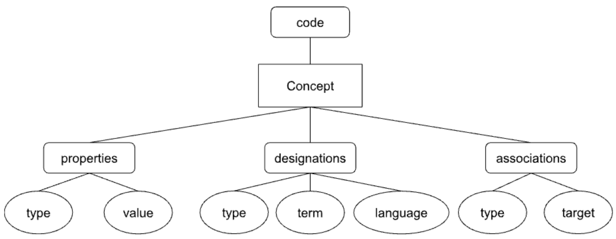


Figure 1: Concept diagramm

A **code system** is a standardized set of codes or symbols representing and communicating various concepts. These codes are essential for organizing and categorizing health data in a consistent and structured manner, facilitating the exchange of information between healthcare professionals, systems, and organizations.

Versioning involves managing and tracking changes to individual concepts and entire code systems. Reasons for concept versioning can be updates in medical knowledge, improvements, clarifications, or incorporating new concepts. Figure 2 shows how the concept versions will be associated with the code system versions.

2 Methodology

In adherence to the principles of Design Science Research Methodology (DSRM), we initiated the TermX Server's design and development process.

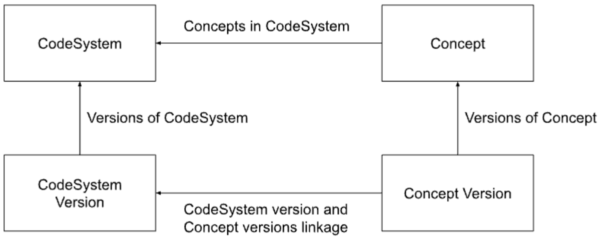


Figure 2: The versioning model in a code system

Meticulously crafting the server, we leveraged standards such as Fast Healthcare Interoperability Resources (HL7 FHIR) and HL7 Common Terminology Services 2 (CTS2) to ensure compatibility and interoperability.

A crucial step involved selecting an appropriate database management system, leading us to choose the relational database management system PostgreSQL for its compatibility with CTS2 and FHIR.

While integrating the CTS2 conceptual model for PostgreSQL, we focused on incorporating the requirements and constraints of the FHIR terminology module to meet established standards.

Upon integrating the CTS2 conceptual model, we compared it to the FHIR conceptual model and developed a transformation process. We actively executed testing and validation processes to guarantee the seamless integration of CTS2 and FHIR.

Throughout the development process, we proactively maintained comprehensive documentation of design knowledge. This documentation encapsulated crucial design decisions and challenges encountered.

3 Results

3.1 CTS2 conceptual model

The conceptual model of the CTS2 contains 30 entities. Figure 3 demonstrates the conceptual model of CTS2. The entities marked with bold frames relate to the code system.

3.2 FHIR terminology conceptual model

The conceptual model of the FHIR Terminology contains 4 entities. Figure 4 demonstrates the conceptual model of the FHIR terminology model.

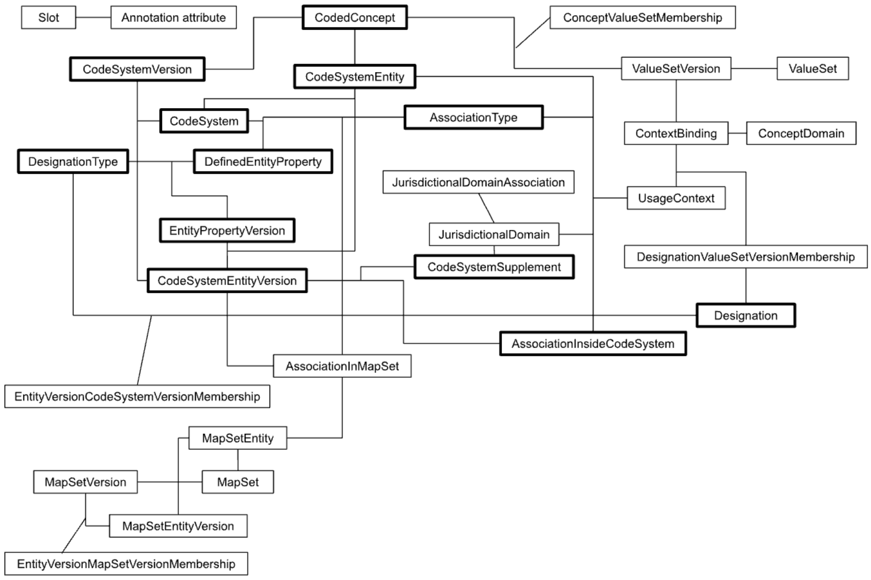


Figure 3: The entities of the CTS2 conceptual model

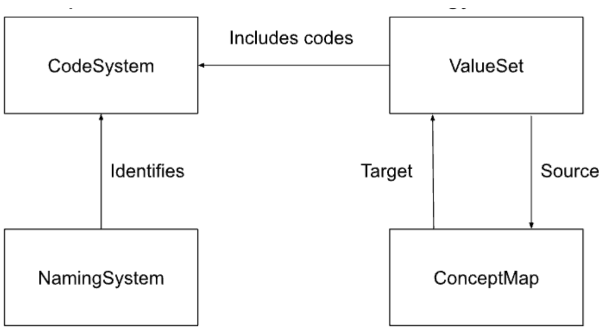


Figure 4: FHIR terminology conceptual model

3.3 The comparison of CTS2 and FHIR conceptual models

In examining the conceptual models of CTS2 and FHIR, notable distinctions that underscore their respective strengths and applications emerge. In FHIR, the absence of divisions into code systems and versions is a distinctive feature. Unlike CTS2, where each version is treated as a separate resource with dedicated organizational structures, FHIR opts for a model where each version exists as an independent resource. Additionally, FHIR needs a dedicated concept resource and needs to incorporate the notion of concept versioning. Consequently, CTS2 stands out as a more comprehensive system, providing a robust version and full authoring capabilities support. The consequence of these differences is evident – CTS2 is a more complete system suitable for tasks involving versioning and comprehensive authoring. At the same time, FHIR is predominantly utilized for the streamlined publication of finished versions.

3.4 Database design

Choosing the CTS2 model as the foundation for our database design was a strategic decision based on a thorough comparison. Illustrated in Figure 5, our database structure mirrors the design of code system entities in the relational database. Leveraging the inherent structure, relationships, and namings in CTS2 conceptual modules, we meticulously adapted these elements during our database design process. Although our use cases didn't necessitate the complete implementation of the CTS2 concept model, we deliberately omitted certain entities (JurisdictionalDomain, UsageContext, ConceptDomain, etc). At the same time, all unused entities can be added as needed. To enhance comprehensibility and readability, we streamlined some of the names, as the intricacies of the CTS2 concept model can be overwhelming. For a more robust querying experience, we introduced new columns and relationships. Moreover, we incorporated additional columns to align with FHIR resources, ensuring a seamless correspondence and meeting the requirements of essential fields.

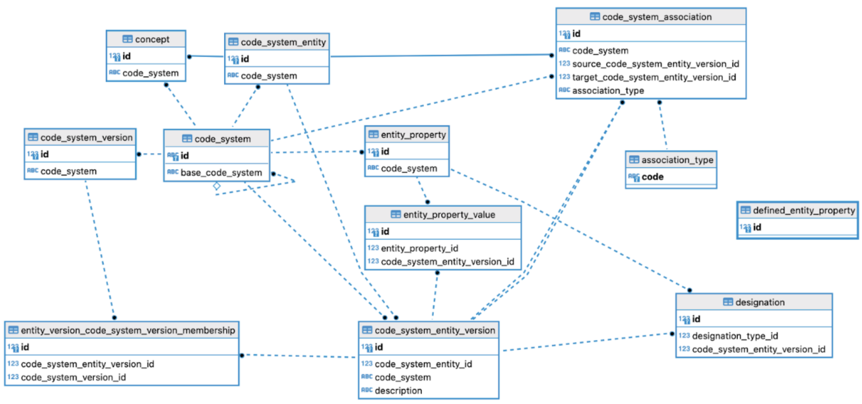


Figure 5: TermX database design of code system entity

Figure 6 shows an example of database data based on the concept from the Logical Observation Identifiers, Names, and Codes (LOINC) code system.

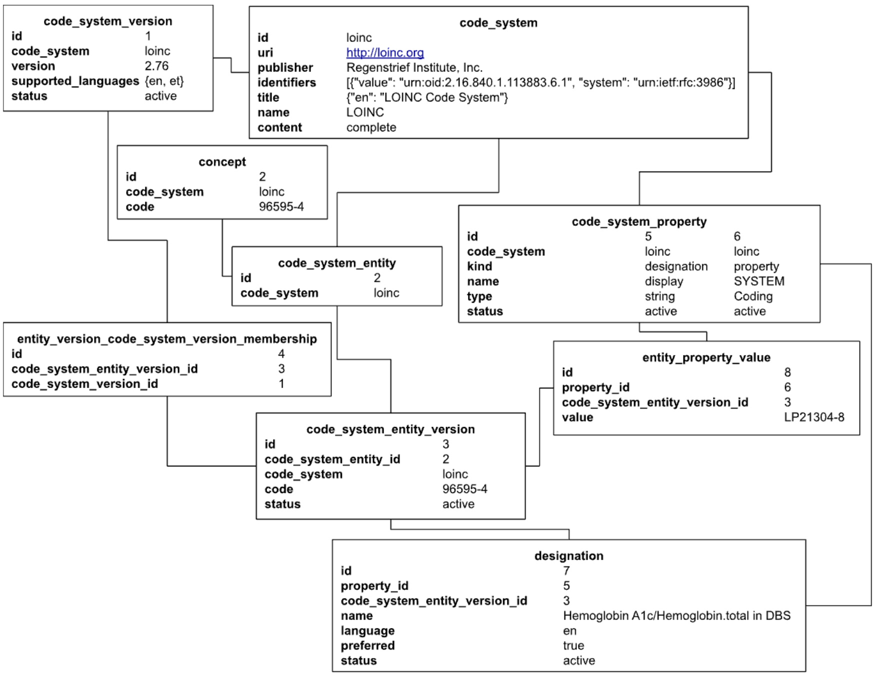


Figure 6: Code system entity example based on LOINC

3.5 CTS2 data model to FHIR terminology resources

As we have shown in comparing CTS2 and FHIR conceptual modules, the FHIR Terminology module is more primitive and may be interpreted as a subset of CTS2. At the same time, the FHIR resources contain some attributes missing in the CTS2. Such attributes include resource URI, both computer- and human-friendly names of the resource, resource authoring information (author, editor, reviewer, endorser), and purpose description of resources. During CTS2 conceptual module implementation in the database and FHIR resource analysis, we added all attributes required by FHIR specification. As a result, there weren't problems with adding FHIR interfaces on top of the extended CTS2 database model. The implemented interfaces for code systems include:

- GET, POST, PUT, DELETE actions for CodeSystem
- HL7 FHIR terminology module operations for CodeSystem: *lookup*, *validate-code*, *subsumes*, *find-matches*

4 Discussion

This discussion segment ventures into the nuanced landscape of challenges encountered during the development of TermX. In this chapter, we unravel specific considerations that have emerged during our journey, addressing intricacies such as resource deletion strategies, versioning complexities between CTS2 and FHIR, flexible data handling capabilities inherent in the CTS2 model, and integrating FHIR constraints.

Implementing resource deletion, particularly for Code Systems, is crucial to ensuring data integrity. The decision to opt for logical deletion, where the resource is marked as deleted but retains its data in the database, is a thoughtful approach. This strategy mitigates the risk of accidental data loss and aligns with best practices in data management. Allowing users to reuse the code of a deleted Code System introduces a layer of flexibility and error prevention.

The disparities between FHIR and CTS2 data models pose challenges, particularly in handling versioning. While FHIR treats each version as a separate resource, CTS2 considers version resources independent entities from the Code System resource. The need to map version codes to FHIR introduces complexities, raising questions about the efficiency of this mapping process and its impact on data consistency.

The discussion on CTS2's flexibility in accommodating data in different formats, such as JSON structures, is noteworthy. The ability to handle diverse languages for fields like title, purpose, and description enhances usability, mainly when the terminology server caters to a wide range of specialists speaking different languages.

Identifying and adding attributes required by FHIR to the CTS2 model for appropriate conversion is critical in ensuring seamless interoperability between the two standards. Also, incorporating FHIR constraints, such as warnings and rules, into the management processes of terminology resources contributes to the overall robustness and reliability of the terminology server.

In conclusion, the challenges and solutions discussed above highlight the intricate nature of implementing a terminology server that aligns with CTS2 and FHIR standards. Future considerations involve refining these implementations based on ongoing feedback, evolving standards, and emerging requirements in the dynamic landscape of healthcare interoperability.

5 Conclusion

In the dynamic realm of healthcare data management, the development and implementation of TermX, an open-source terminology server, marks a significant stride towards achieving comprehensive interoperability and data standardization. This article has delved into the intricacies of implementing the Common Terminology Services 2 (CTS2) standard on PostgreSQL while integrating with HL7 Fast Healthcare Interoperability Resources (FHIR). As we conclude this exploration, several vital takeaways emerge:

- *Standardization and Interoperability*: Implementing CTS2 as a data model ensures adherence to widely recognized standards, fostering consistency and interoperability across diverse healthcare systems and applications. CTS2's flexibility and support for mapping contribute to seamless integration, addressing the complexities of varied coding schemes.

- *Database Management with PostgreSQL*: The strategic choice of PostgreSQL as the database management platform underscores the commitment to data integrity, security, and accessibility in healthcare settings. Using PostgreSQL's advanced features, including indexing options, complex query support, and JSONB capabilities, enhances the efficiency and flexibility of clinical terminology management.

- *TermX Innovation and FHIR Integration*: TermX stands out as an innovative platform, embracing the latest standards, enhancing import capabilities, and supporting FHIR to meet the evolving demands of modern healthcare. Integrating FHIR resources, including CodeSystem, ValueSet, and ConceptMap, underscores TermX's commitment to semantic interoperability and data consistency.

- *Addressing Versioning Challenges*: The discussion on versioning complexities between CTS2 and FHIR models highlights the nuanced nature of terminology management. Considering logical deletion, code system reuse, and the challenges in mapping version codes between standards reflects a commitment to comprehensive data governance and error prevention.

- *CTS2 Flexibility and Attribute Mapping*: The recognition of CTS2's flexibility in handling data in different formats and languages showcases a forward-looking approach to catering to a diverse user base. Attribute mapping to accommodate FHIR requirements demonstrates a meticulous effort to align with standards and ensure seamless conversion between data models.

- *FHIR Constraints for Robust Resource Management*: Incorporating FHIR constraints, including warnings and rules, in the management processes of terminology resources adds an extra layer of reliability. This proactive approach enhances the robustness of the terminology server, contributing to the overall quality and consistency of healthcare data.

TermX emerges as a technological solution and a testament to the commitment to advancing healthcare interoperability. The comprehensive exploration of its implementation, from the choice of standards to database design and FHIR integration, lays the foundation for future innovations in clinical terminology management. As the healthcare landscape evolves, TermX stands ready to adapt, ensuring it remains at the forefront of facilitating a seamless, interoperable, standardized healthcare ecosystem.

Code availability

The TermX terminology server has been published as an open-source library on GitLab [10, 11] and integrated into the TermX interoperability platform [12].

Authors' contribution

M.I. designed the idea and wrote the manuscript with support from I.B. All authors contributed to the final version. G.P. supervised the project.

M.I. and I.B. designed the solution and architecture of the TermX terminology server, which M.I. developed with the support of I.B. and Daniel Dubrovski.

References

[1] M. Lehne, J. Sass, A. Essenwanger, J. Schepers, and S. Thun, "Why digital medicine depends on interoperability," *NPJ digital medicine*, vol. 2, no. 1, p. 79, 2019.

[2] HL7, "Fhir terminology module." `http://hl7.org/fhir/terminology-module.html`, 2023.

[3] B. Blobel *et al.*, "Cts2 owl: Mapping owl ontologies to cts2 terminology resources," in *PHealth 2022: Proceedings of the 19th International Conference on Wearable Micro and Nano Technologies for Personalized Health*, vol. 299, p. 44, IOS Press, 2022.

[4] R. Gazzarata, N. Maggi, L. D. Magnoni, M. E. Monteverde, C. Ruggiero, and M. Giacomini, "Semantics management for a regional health information system in italy by cts2 and fhir," in *Applying the FAIR Principles to Accelerate Health Research in Europe in the Post COVID-19 Era: Proceedings of the 2021 EFMI Special Topic Conference*, vol. 287, p. 119, IOS Press, 2021.

[5] OMG, "Common terminology services 2." `https://www.omg.org/spec/CTS2`, 2023.

[6] HL7, "Hl7 common terminology services. service functional model specification. release 2." `http://www.hl7.org/documentcenter/private/standards/CTS/V3_CTS2_r2_2015FEB_R2022.pdf`, 2022.

[7] T. P. G. D. Group, "About postgresql." `https://www.postgresql.org/about`, 2023.

[8] T. Austin, S. Sun, Y. S. Lim, D. Nguyen, N. Lea, A. Tapuria, D. Kalra, *et al.*, "An electronic healthcare record server implemented in postgresql," *Journal of healthcare engineering*, vol. 6, pp. 325–344, 2015.

[9] Y. Havinga, W. Dijkstra, and A. de Keijzer, "Adding hl7 version 3 data types to postgresql," *arXiv preprint arXiv:1003.3370*, 2010.

[10] Kodality, "Termx. terminology server based on cts2." `https://gitlab.com/kodality/terminology/termx-server`, 2023.

[11] Kodality, "Termx web." `https://gitlab.com/kodality/terminology/termx-web`, 2023.

[12] Kodality, "Termx tutorial." `https://termx.kodality.dev/wiki/termx-tutorial/about`, 2023.