

10 Years Later: The Mathematics Subject Classification and Linked Open Data

Susanne Arndt, Patrick Ion, **Mila Runnwerth**, Moritz Schubotz, Olaf Teschke



A Short History of the MSC

AMERICAN MATHEMATICAL SOCIETY
MathSciNet[®]
Mathematical Reviews

zbMATH  **Open**^{*}
THE FIRST RESOURCE FOR MATHEMATICS

The Mathematics Subject Classification (MSC) is an indexing schema for mathematics used in libraries, publishing houses, and research institutions to classify and sort mathematical information or research activity.

The MSC is updated every decade.

* [Here are the latest news about zbMATH Open. Check it out!](#)

A Short History of the MSC (and where to find it)



A Short History of the MSC

(in Facts & Numbers)

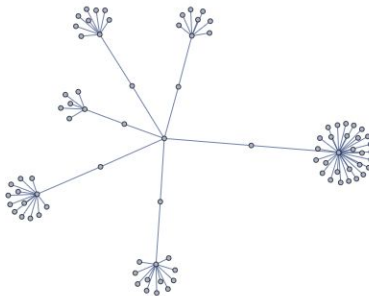
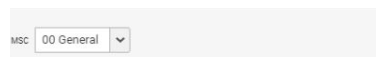
63 top level classes, e.g., 14-XX

1.037 second level classes, e.g., 14Axx

5.503 third level classes, e.g., 14A05

Meta classes for:
reference works, biographies, software
& research data, conference
proceedings

Source: <https://demonstrations.wolfram.com/MathematicsSubjectClassificationGraphs/>



Mathematics Subject Classification – MSC2020

MSC2020 is the latest revision of the Mathematics Subject Classification (MSC), jointly published by Mathematical Reviews and zbMATH Open under a Creative Commons CC-BY-NC-SA license. It replaces the 2010 Mathematics Subject Classification. For more details on the revision, read more in the article <https://doi.org/10.4171/NEWS/115/2>.

- | | | |
|--|---|--|
| 00 General and overarching topics; collections | 65 Numerical analysis | 62 Statistics |
| 01 History and biography | 65 Numerical analysis | 65 Numerical analysis |
| 03 Mathematical logic and foundations | 35 Partial differential equations | 68 Computer science |
| 05 Combinatorics | 37 Dynamical systems and ergodic theory | 70 Mechanics of particles and systems |
| 06 Order, lattices, ordered algebraic structures | 39 Difference and functional equations | 74 Mechanics of deformable solids |
| 08 General algebraic systems | 40 Sequences, series, summability | 76 Fluid mechanics |
| 11 Number theory | 41 Approximations and expansions | 78 Optics, electromagnetic theory |
| 12 Field theory and polynomials | 42 Harmonic analysis on Euclidean spaces | 80 Classical thermodynamics, heat transfer |
| 13 Commutative algebra | 43 Abstract harmonic analysis | 81 Quantum theory |
| 14 Algebraic geometry | 44 Integral transforms, operational calculus | 82 Statistical mechanics, structure of matter |
| 15 Linear and multilinear algebra; matrix theory | 45 Integral equations | 83 Relativity and gravitational theory |
| 16 Associative rings and algebras | 46 Functional analysis | 85 Astronomy and astrophysics |
| 17 Nonassociative rings and algebras | 47 Operator theory | 86 Geophysics |
| 18 Category theory; homological algebra | 49 Calculus of variations and optimal control; optimization | 90 Operations research, mathematical programming |
| 19 K-theory | 51 Geometry | 91 Game theory, economics, finance, and other social and behavioral sciences |
| 20 Group theory and generalizations | 52 Convex and discrete geometry | 92 Biology and other natural sciences |
| 22 Topological groups, Lie groups | 53 Differential geometry | 93 Systems theory; control |
| 26 Real functions | 54 General topology | 94 Information and communication theory, circuits |
| 28 Measure and integration | 55 Algebraic topology | 97 Mathematics education |
| 30 Functions of a complex variable | 57 Manifolds and cell complexes | |
| 31 Potential theory | 58 Global analysis, analysis on manifolds | |
| 32 Several complex variables and analytic spaces | 60 Probability theory and stochastic processes | |
| 33 Special functions | | |

Source: <https://zbmath.org/classification/>

A Review of the SKOSified MSC 2010

Motivation



- deriving formats from an LOD version: pdf, html, LaTeX
- semantic applications
- visualisation
- mapping to other classifications
- open maintenance / editorial process

LANGE, Christoph, et al. Reimplementing the mathematics subject classification (MSC) as a linked open dataset. In: *International Conference on Intelligent Computer Mathematics*. Springer, Berlin, Heidelberg, 2012. S. 458-462.
<https://arxiv.org/abs/1204.5086>.



SKOS Core
msc mscvocab
rdf rdfs xml xsd
dc foaf

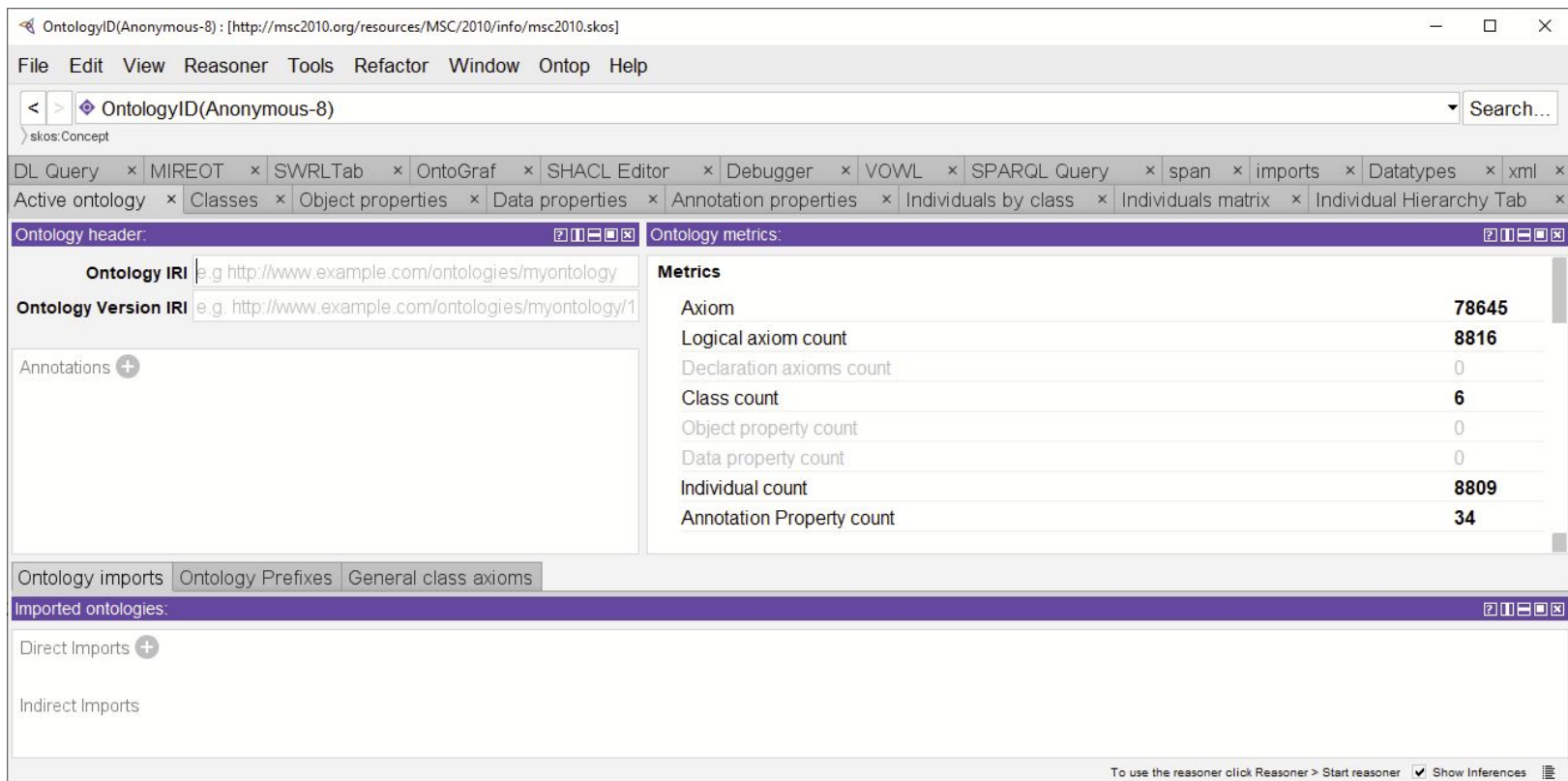
MSC specific references (selection):

- see also
- see mainly
- related part of
- see conditionally

01-XX History and biography [See also the classification number -03 in the other sections]



A Review of the SKOSified MSC 2010 (in Protégé)



OntologyID(Anonymous-8) : [http://msc2010.org/resources/MS/2010/info/msc2010.skos]



File Edit View Reasoner Tools Refactor Window Ontop Help

< > OntologyID(Anonymous-8) Search...

> skos:Concept


DL Query x MIREOT x SWRLTab x OntoGraf x SHACL Editor x Debugger x VOWL x SPARQL Query x span x imports x Datatypes x xml x

Active ontology x Classes x Object properties x Data properties x Annotation properties x Individuals by class x Individuals matrix x Individual Hierarchy Tab x

Ontology header:  Ontology metrics: 

Ontology IRI: e.g. http://www.example.com/ontologies/myontology


Ontology Version IRI: e.g. http://www.example.com/ontologies/myontology/1


Annotations 

Metrics


Axiom	78645
Logical axiom count	8816
Declaration axioms count	0
Class count	6
Object property count	0
Data property count	0
Individual count	8809
Annotation Property count	34

Ontology imports | Ontology Prefixes | General class axioms

Imported ontologies: 

Direct Imports 

Indirect Imports

To use the reasoner click Reasoner > Start reasoner Show Inferences 

A Review of the SKOSified MSC 2010

```
<rdf:RDF>
  <script id="__gaOptOutExtension"/>
  <Concept rdf:about="http://msc2010.org/resources/MSC/2010/68-XX">
    <msc:matchDewey rdf:resource="http://dewey.info/class/004/2009/08"/>
    <msc:seeConditionally rdf:resource="http://msc2010.org/resources/MSC/2010/Section--04 in that area"/>
    <msc:seeFor rdf:resource="http://msc2010.org/resources/MSC/2010/68-XX-to-Section--04 in that area-seeFor"/>
    <seeAlso rdf:resource="http://msc2010.org/resources/MSC/2010/Section--04 in that area"/>
    <altLabel xml:lang="en">
      Computer science {For papers involving machine computations and programs in a specific mathematical area see Section--04 in that area}
    </altLabel>
    <historyNote rdf:resource="http://msc2010.org/resources/MSC/2010/68-XX-formerly-1991"/>
    <historyNote rdf:resource="http://msc2010.org/resources/MSC/2010/68-XX-formerly-2000"/>
    <inScheme rdf:resource="http://msc2010.org/resources/MSC/2010/MSC2010"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-00"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-01"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-02"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-03"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-04"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68-06"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Mxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Nxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Pxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Qxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Rxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Txx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Uxx"/>
    <narrower rdf:resource="http://msc2010.org/resources/MSC/2010/68Wxx"/>
    <notation rdf:datatype="http://msc2010.org/resources/MSC/2010/msc:vocab#MSCNotation">68-XX</notation>
  </note>
  For papers involving machine computations and programs in a specific mathematical area, see Section--04 in that area.
</note>
<prefLabel xml:lang="en">Computer science</prefLabel>
<prefLabel xml:lang="zh">计算机科学(特殊数学领域中涉及机器计算和程序的论文, 见有关领域_04部分)</prefLabel>
<semanticRelation rdf:resource="http://msc2010.org/resources/MSC/2010/Section--04 in that area"/>
<topConceptOf rdf:resource="http://msc2010.org/resources/MSC/2010/MSC2010"/>
</Concept>
</rdf:RDF>
```

URI resolves to a per-concept-documentation

<http://msc2010.org/resources/MSC/2010/68-XX>

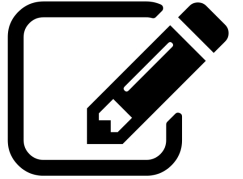


A Review of the first SKOSified MSC 2010

Lessons learned for editing & SKOSifying the MSC 2020

- standardisation of relations
- separation of unique class names and descriptions

- fix misconstructured identifiers (spaces or special characters in URIs)
- reifications with RDF terms
- correct wrongly applied datatype “XMLLiteral”
- review of the lost & found *mscvocab* extension



A SKOS version for the MSC 2020

Motivation - specific use cases are waiting

- automated indexing in libraries with annif
- extensive classification mapping
- mathematical template for the [ORKG](#)
- provision via terminology services in research data management (see [MaRDI](#))

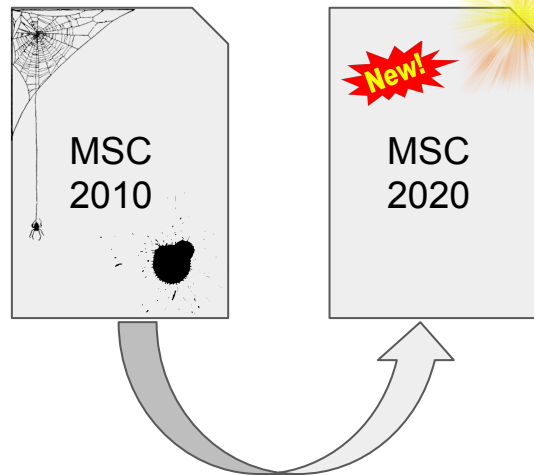
Formula representation

consistently in HTML: MathML

$(a+b)^2$

```
<mrow>
  <apply>
    <power/>
    <apply>
      <plus/>
      <ci>a</ci>
      <ci>b</ci>
    </apply>
    <cn>2</cn>
  </apply>
</mrow>
```

Automation



OpenRefine, Protégé, EXCEL

License



Languages



https://github.com/runwerth/MS2020_SKOS

A SKOS version for the MSC 2020 (in Protégé)

The screenshot shows the Protégé ontology editor interface. The main window title is "MSC2020 (https://msc2020.org/resources/MSC/2020/MSC2020/0.0.0)". The menu bar includes File, Edit, View, Reasoner, Tools, Refactor, Window, Ontop, and Help. The toolbar shows navigation and search options. The main workspace is divided into several panels:

- Ontology header:** Displays the ontology IRI and version IRI, both pointing to <https://msc2020.org/resources/MSC/2020/MSC2020/>.
- Annotations:** Shows a list of annotations for the class MSC2020, including `dc:title` (MSC2020) and `dc:description` (Mathematics Subject Classification 2020 Edition).
- Ontology metrics:** A table showing various counts for the ontology.
- Imported ontologies:** Shows direct imports, including `<http://www.w3.org/1999/02/22-rdf-syntax-ns#>` (22-rdf-syntax-ns).

Metrics	
Axiom	67912
Logical axiom count	40021
Declaration axioms count	7119
Class count	29
Object property count	35
Data property count	1
Individual count	13217
Annotation Property count	32

At the bottom of the window, there is a status bar with "Git: main" on the left and "To use the reasoner click Reasoner > Start reasoner" and "Show Inferences" on the right.

A SKOS version for the MSC 2020

Reification for conditional references between concepts:

```
<https://msc2020.org/resources/MS/2020/MS2020/03B45> mscvocab:seeFor msc:SeeForStatement-03B45-to-03B42 .
```

```
msc:SeeForStatement-03B45-to-03B42 rdf:type owl:NamedIndividual ,  
    mscvocab:SeeForStatement ;  
    rdf:object <https://msc2020.org/resources/MS/2020/MS2020/03B42> ;  
    rdf:predicate mscvocab:seeConditionally ;  
    rdf:subject <https://msc2020.org/resources/MS/2020/MS2020/03B45> ;  
    mscvocab:scope "For knowledge and belief"@en .
```

A SKOS version for the MSC 2020

<<https://msc2020.org/resources/MSC/2020/MSC2020/01A99>>

Outgoing Links

rdf.type	skos:Concept
skos.broader	https://msc2020.org/resources/MSC/2020/MSC2020/01Axx
skos.inScheme	https://msc2020.org/resources/MSC/2020/MSC2020/
rdf.type	owl:NamedIndividual
skos.closeMatch	http://msc2010.org/resources/MSC/2010/msc2010/01A99

← explicit relations to MSC 2010 predecessor

Incoming Links

https://msc2020.org/resources/MSC/2020/MSC2020/HistoricalCollection	skos:member
---	-----------------------------

← concept collections for specific topics

Attributes

skos:notation	01A99	change notes
skos.prefLabel	Geschichte der Mathematik und Mathematiker	
skos.prefLabel	History of mathematics and mathematicians	↙
skos.scopeNote	None of the above, but in this section	
dcterms.description	description text changed in comparison to MSC 2010 (skos:prefLabel and description (skos:scopeNote in MSC 2020) were changed)	

A look at a single concept

The screenshot displays the Protégé OWL editor interface. The main window shows the concept `owl:Thing` selected in the left-hand pane. The right-hand pane displays the annotations for the selected concept, including:

- `skos:prefLabel` [language: en] Applications of differential geometry to sciences and engineering
- `skos:prefLabel` [language: de] Anwendungen der Differentialgeometrie an und Ingenieurwissenschaften
- `dc:dcterms:description` [language: en] description text changed in comparison to MSC 2010 (skos:prefLabel changed)
- `skos:scopeNote` [language: en] None of the above, but in this section

The bottom-left pane shows a class hierarchy with the following structure:

- Geometry education
 - General models, approaches, and methods
 - Equilibrium (steady-state) problems in solid mechanics
 - General aerodynamics and subsonic flows
 - Relations of manifolds and cell complexes with science and engineering
 - Applications of global analysis to the sciences
 - Differential calculus (educational aspects)
 - Homological methods (field theory)
 - Arithmetic algebraic geometry (Diophantine geometry)
 - Algebraic logic
 - Applications of differential geometry to sciences and engineering**
 - Applications to the sciences
 - Integral calculus (educational aspects)
 - Research data for problems pertaining to field theory
 - Linear algebraic groups and related topics
 - Representation theory of associative rings and algebras
 - Arithmetic problems in algebraic geometry; Diophantine geometry

The bottom-right pane shows the property assertions for the selected concept, including:

- `skos:closeMatch` `<http://msc2010.org/resources/MSC/2010/msc2010/53Z99>`
- `skos:broadener` 'Applications of differential geometry to sciences and engineering'
- `skos:inScheme`
- `skos:notation` "53Z99"^^xsd:string

The status bar at the bottom indicates the current ontology is `MSC2020` and provides options to use the reasoner and show inferences.

A look at a single concept

```
<!-- https://msc2020.org/resources/MSC/2020/MSC2020/53Z99 -->
```

```
<owl:NamedIndividual rdf:about="https://msc2020.org/resources/MSC/2020/MSC2020/53Z99">  
<rdf:type rdf:resource="http://www.w3.org/2004/02/skos/core#Concept"/>  
<skos:broader rdf:resource="https://msc2020.org/resources/MSC/2020/MSC2020/53Zxx"/>  
<skos:closeMatch rdf:resource="http://msc2010.org/resources/MSC/2010/msc2010/53Z99"/>  
<skos:inScheme rdf:resource="https://msc2020.org/resources/MSC/2020/MSC2020"/>  
<skos:notation rdf:datatype="http://www.w3.org/2001/XMLSchema#string">53Z99</skos:notation>  
<dc:description xml:lang="en">description text changed in comparison to MSC 2010 (skos:prefLabel changed)</dc:description>  
<skos:prefLabel xml:lang="de">Anwendungen der Differentialgeometrie in den Natur- und Ingenieurwissenschaften</skos:prefLabel>  
<skos:prefLabel xml:lang="en">Applications of differential geometry to sciences and engineering</skos:prefLabel>  
<skos:scopeNote xml:lang="en">None of the above, but in this section</skos:scopeNote>  
</owl:NamedIndividual>
```

Outlook - Our house

We need to build a proper 'home' for all versions

- resolving the URIs to a documentation site
- providing a SPARQL endpoint
- reliable and sustainable citation



Source: Giphy

Current workaround

- <http://purl.org/msc2020/mscvocab>
- <http://purl.org/msc2020/msc>
- <https://sparql.arg20.formulasearchengine.com/bigdata/#query>
- Wikibase Query Service instance for MSC 2020: <https://query.arg20.formulasearchengine.com/>

(see the following example)

Query meaning: Show me all concepts of MSC 2020 that were changed in comparison to MSC 2010, what change was made, and which MSC 2010 concept the concepts were derived from.



DockerWikibaseQueryService

Beispiele

Hilfe

Weitere Werkzeuge



```
1 prefix dct: <http://purl.org/dc/terms/>
2
3 select ?s ?desc ?p ?y
4 where
5 {?s a skos:Concept .
6 MINUS {?s skos:exactMatch ?y}
7 ?s ?p ?o .
8 ?s skos:inScheme <https://msc2020.org/resources/MSC/2020/MSC2020/> .
9 #?y skos:inScheme <http://msc2010.org/resources/MSC/2010/msc2010/>.
10 ?s dct:description ?desc .
11 ?s ?p ?y .
12 ?y a skos:Concept .}
13 order by ?s
14 #limit 100
```

<https://tinyurl.com/yzbna22x>

Outlook - Let's come together

- Would you like to provide more languages?
- Would you like to participate in the editing process for MSC 2030?
- Would you like to help us to maintain / modularise this monster file?
- Do you have further use cases?



Source: Giphy

WHY DO WHALES JUMP
WHY ARE WITCHES GREEN
 WHY ARE THERE MIRRORS ABOVE BEDS
WHY DO I SAY UH
WHY IS SEA SALT BETTER
 WHY ARE THERE TREES IN THE MIDDLE OF FIELDS
WHY IS THERE NOT A POKEMON MMO
WHY IS THERE LAUGHING IN TV SHOWS
WHY ARE THERE DOORS ON THE FREEWAY
WHY ARE THERE SO MANY SUCHOSTEXE RUNNING
WHY AREN'T THERE ANY COUNTRIES IN ANTARCTICA
WHY ARE THERE SCARY SOUNDS IN MINECRAFT
WHY IS THERE KICKING IN MY STOMACH
WHY ARE THERE TWO SLASHES AFTER HTTP
WHY ARE THERE CELEBRITIES
WHY DO SNAKES EXIST
WHY DO OYSTERS HAVE PEARLS
WHY ARE DUCKS CALLED DUCKS
WHY DO THEY CALL IT THE CLAP
WHY ARE KYLE AND CARTMAN FRIENDS
WHY IS THERE AN ARROW ON AANG'S HEAD
WHY ARE TEXT MESSAGES BLUE
WHY ARE THERE MUSTACHES ON CLOTHES
WHY ARE THERE MUSTACHES ON CARS
WHY ARE THERE MUSTACHES EVERYWHERE
WHY ARE THERE SO MANY BIRDS IN OHIO
WHY IS THERE SO MUCH RAIN IN OHIO
WHY IS OHIO WEATHER SO WEIRD
WHY ARE THERE MALE AND FEMALE BIKES
WHY ARE THERE BRIDESMAIDS
WHY DO DYING PEOPLE RECALL LIF
WHY AREN'T THERE VORLAGE PRISERS
WHY ARE OLD KINGDOMS DIFFERENT
WHY ARE THERE TINY SPIDERS IN MY HOUSE
WHY DO SPIDERS COME INSIDE
WHY ARE THERE HUGE SPIDERS IN MY HOUSE
WHY ARE THERE LOTS OF SPIDERS IN MY HOUSE
WHY ARE THERE SPIDERS IN MY ROOM
WHY ARE THERE SO MANY SPIDERS IN MY ROOM
WHY DO SPIDER BITES ITCH
WHY IS DYING SO SCARY
WHY IS THERE NO GPS IN LAPTOPS
WHY DO KNEES CLICK
WHY AREN'T THERE E GRADERS
WHY IS ISOLATION BAD
WHY DO BOYS LIKE ME
WHY DON'T BOYS LIKE ME
WHY IS THERE ALWAYS A JAVA UPDATE
WHY ARE THERE RED DOTS ON MY THIGHS
WHY IS LYING GOOD
WHY IS SEX SO IMPORTANT
WHY IS THERE AN OWL IN MY BACKYARD
WHY IS THERE AN OWL OUTSIDE MY WINDOW
WHY IS THERE AN OWL ON THE DOLLAR BILL
WHY DO OWLS ATTACK PEOPLE
WHY ARE AK 47S SO EXPENSIVE
WHY ARE THERE HELICOPTERS CIRCLING MY HOUSE
WHY ARE THERE GODS
WHY ARE THERE TWO SPOCKS
WHY IS MT VESUVIUS THERE
WHY DO THEY SAY T MINUS
WHY ARE THERE OBELISKS
WHY ARE WRESTLERS ALWAYS WET
WHY ARE OCEANS BECOMING MORE ACIDIC
WHY IS ARWEN DYING
WHY AREN'T MY QUAIL LAYING EGGS
WHY AREN'T MY QUAIL EGGS HATCHING
WHY AREN'T THERE ANY FOREIGN MILITARY BASES IN AMERICA
WHY ARE THERE SO MANY CROWS IN ROCHESTER,
WHY ARE THERE 50 CROWS IN ROCHESTER,
WHY IS PSYCHIC WEAK TO BUG
WHY DO CHILDREN GET CANCER
WHY IS POSEIDON ANGRY WITH ODYSSEUS
WHY IS THERE ICE IN SPACE
WHY ARE THERE DOGS AFRAID OF FIREWORKS
WHY IS THERE NO KING IN ENGLAND
WHY AREN'T MY ARMS GROWING
WHY AREN'T THERE GUNS IN HARRY POTTER

QUESTIONS FOUND IN GOOGLE AUTOCOMPLETE

