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Whose knowledge? Whose questions? Whose answers?

Conflicting Preconceptions for Knowledge Intensive Systems

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with thanks to
Jeremy Rogers, Anthony Nowlan, and the SWBP, OWL, CO-ODE & Protégé teams

Open GALEN

protégé

cooperative ontologies programme

JISC The Joint Information Systems Committee

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This should be the age of knowledge acquisition

- The Web
  - Social computing & Web II
  - The Semantic Web/Grid
- Service oriented Architectures and discovery
  - Digital libraries, repositories, ...
  - Semantic computing
- "Ontologies with everything"
- ...
- ...

"... but couldn't we just get back to 1985"

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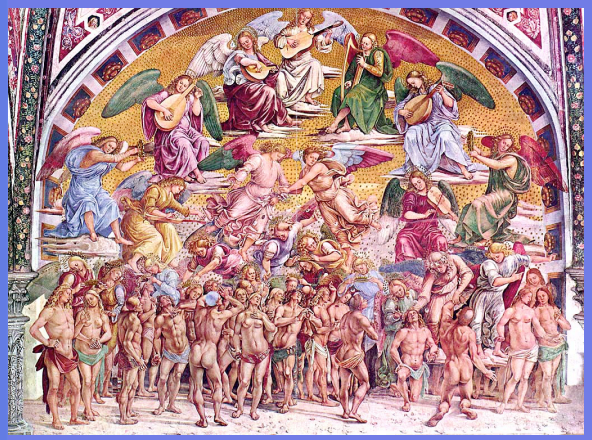

- **Problem space**
  - Answer questions
  - Advising on actions
  - Hazard monitoring
  - Creating forms
  - Discovering resources
  - Constraint actions
  - Assess risk
  - …

- **Solution space**
  - Logics
  - Rules
  - Frames
  - Planners
  - Logic programming
  - Bayes nets
  - Decision theory
  - Fuzzy sets
  - Open / closed world
  - …

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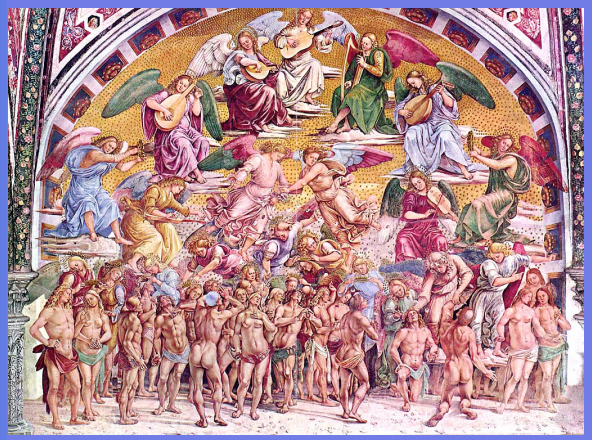

Knowledge Acquisition

- **Solution space**
  - Logics
  - Rules
  - Frames
  - Planners
  - Logic programming
  - Bayes nets
  - Decision theory
  - Fuzzy sets

- **Problem space**
  - Answer questions
  - Advising on actions
  - Hazard monitoring
  - Creating forms
  - Discovering resources
  - Constraint actions
  - Assess risk
  - …

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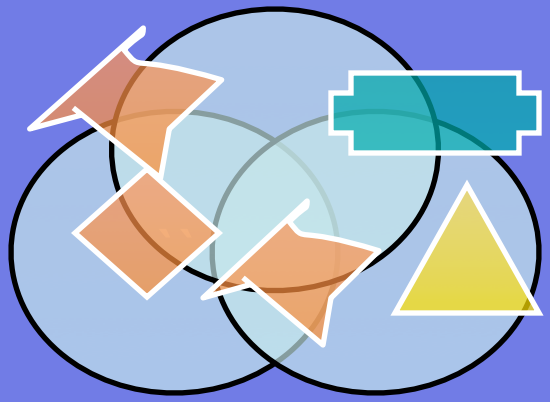
Problem space & solution space

Problem space

Guidelines, Patterns, Tools,...
Knowledge Acquisition

Solution space



The knowledge principle

- ***A system exhibits intelligent understanding and action at a high level of competence primarily because of the specific knowledge that it contains about its domain of endeavor*.**
  - **Ed Feigenbaum: The Age of Intelligent Machines: Knowledge Processing--From File Servers to Knowledge Servers, 1990**

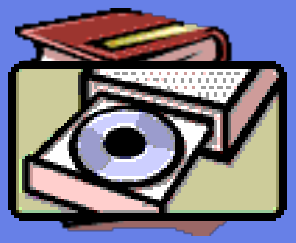
- **Knowledge comes from domain experts:** ***Derived from and delivered to the problem space***

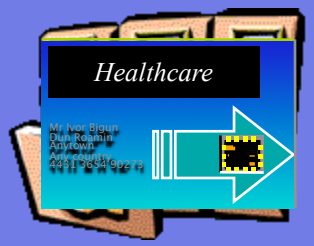
…and a Key Reference Point

- *We argue that logical soundness, completeness, and worst-case complexity are inadequate measures for evaluating the utility of representation services, and that this evaluation should employ the broader notions of utility and rationality …"*
  - Two theses of knowledge representation: Language restrictions, taxonomic classification and the utility of representation services.
    Doyle, J and Patil, R, Artificial Intelligence, 1991. 48: p. 261-297

Where I come from

Clinical Terminology ← Data Entry ← Clinical Record ← Clinical research & Decision Support ← Best Practice





GALEN Ontologies & Description logics → Data Entry → Electronic Health Records → Clinical research Decision Support & Knowledge Presentation → **Best Practice**

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By way of User Centred Design

Ontologies were a solution, not a goal

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… and now to

- BioOntologies, Anatomy, and Molecular Pathways
  - Capturing biologists knowledge
  - Reconciling diverse views / Avoiding ontological dogmatism
  - Integrating ≥500 sources
- Healthcare record standards: Data models and Terminology
  - Improving the rigour of "UML" based message standards
  - Binding of terminology to data models
- Medical terminologies / ontologies
  - GALEN, SNOMED, NCI thesaurus
- Forms generation for clinical trials, data entry & entry and decision support.
  - PEN&PAD Revisited
- User oriented Ontology Tools - CO-ODE/Protégé-OWL
- Semantic Web Best Practice WG & Healthcare & Life Sciences SIG (& campaigner for OWL 1.1 and beyond)

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Some Recent User Experiences

- Two companies building clinical systems
  - Intelligent forms creation and constraint management
    - Mastering a combinatorial explosion of $\geq 10^7$
  - Workshops, Training and subcontracting
- NHS National Programme for IT:
  - Additional constraints to UML and between UML and terminology/ontology
    - Different implementation of the standard don't fit
  - Managing SNOMED
    - Large ≥450K ters DL based terminology
- Biologists research groups
  - Many clinics and workshops
    - indefinitely many emails on HCLSig
- The Anatomy community
  - Workshops towards a common vertebrate anatomy
- "Can't we just get back to 1985"

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What are my prejudices?

- "First do the right thing; then do it right"
  - and hope that by the time you know what to do someone else can show you how
- *"There is no one way!"*
  - "Society for the Promotion of Secular Ontology"
- "Better" is better than "best"
  - The best is often the enemy of the good
- *Unobtrusive assistance is better than advice*
  - "Shedding light" rather than "uttering prophecies"
- *"It doesn't make the coffee!"*
  - Nothing does everything - the secret is in factoring the solution space to fit the problem space

Who are my users?

- Intermediate users
  - Clinical terminologies developers
    - GO, SNOMED, GALEN, CCAM, FMA, …
  - IT staff configuring clinical systems
    - NHS, Healthcare information systems staff
  - Standards developers
    - BioPAX, HL7, ??ML,…,
- Near to end users
  - Bioinformaticians
  - Trialists and other specialist healthcare informaticians
- End users
  - Biolomedical scientists
  - Clinicians, carers and patients

The rest of the talk

- Our experiences
  - Our original application: Fractal tailoring of data input forms
  - Building large terminologies
    - Logic as the clips for "Conceptual Lego"
    - Untangling and normalisation
  - Working with biologists
- Observations on Knowledge Resources and "Ontologies"
  - Things we have found
  - Things we need

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Where we started: A Vision

- Useful and Usable clinical systems
  - Information when and where you need it
    - to make better decisions
      - *"Shedding light"*
      - *"Cuing"*
  - In your own language
- Aggregated data as a byproduct of clinical
- …without getting caught in the combinatorial explosion

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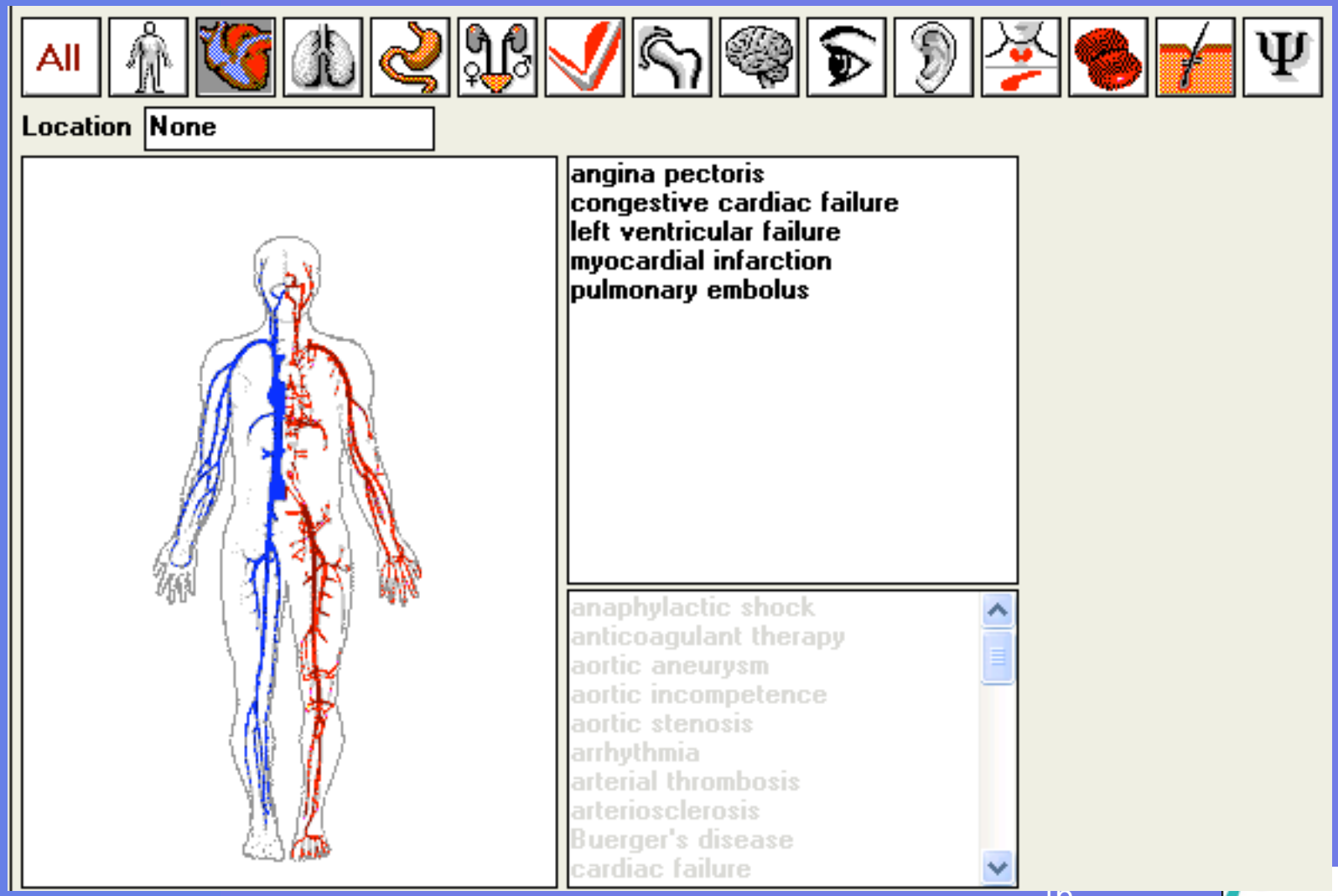
Clinergy/ Pen&PAD



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Forms

Topics | Angina pectoris

Descriptors

Presence: present | possible | excluded

Duration: 1 days

Severity: mild | moderate | severe

Progress: better | same | worse

Associated Symptoms all...

Chest pain: absent | present | more...

Arm pain: absent | present | more...

Further History

FH | PMH | SH

Examinations all...

Examination: normal

Cardiovascular system: normal | more...

Pulse rate: 70 Per minute

Blood pressure

Systolic BP: 120 Mm Hg

Diastolic BP: 80 Mm Hg

Diagnoses all...

Interventions all...

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and more forms

Topics | Angina pectoris

Descriptors

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Associated Symptoms all...

Chest pain: absent | present | more...

Further H

Examinati

Cardiov

Diagnose

Interventi

More on Chest pain

Descriptors

Chest pain: absent | present

Sublocation: left chest | right chest | clavicular region | sternal region | anterior ribs region | posterior ribs region | sternoclavicular joint | costochondral joint

Duration: days

Character: aching | piercing | dull | throbbing | pressing | burning | crushing

Severity: mild | moderate | severe

Onset: gradual | rapid | sudden

>>

Accept | Reset | Cancel

Generated Text

Summary

Moderately severe angina pectoris for 1 day, getting worse
Rapid onset, moderately severe, pressing pain in left chest and sternal region present
No arm pain

One of the great missed opportunities today

See Donia Scott's work at OU

Moderately severe, localised, piercing pain in costochondral joint for 3 days [182.]
No cough [11Z.]
No dyspnoea [11Z.]
Blood pressure 130/80 mm Hg [24..]
Respiratory system normal [23..]
Chest: acute tenderness of costochondral joint [23..]
Costochondritis [M5**]
Moderately severe angina pectoris for 1 day, getting worse [G44.]
Sudden onset, moderately severe, pressing pain

And automatic (Read) code generation

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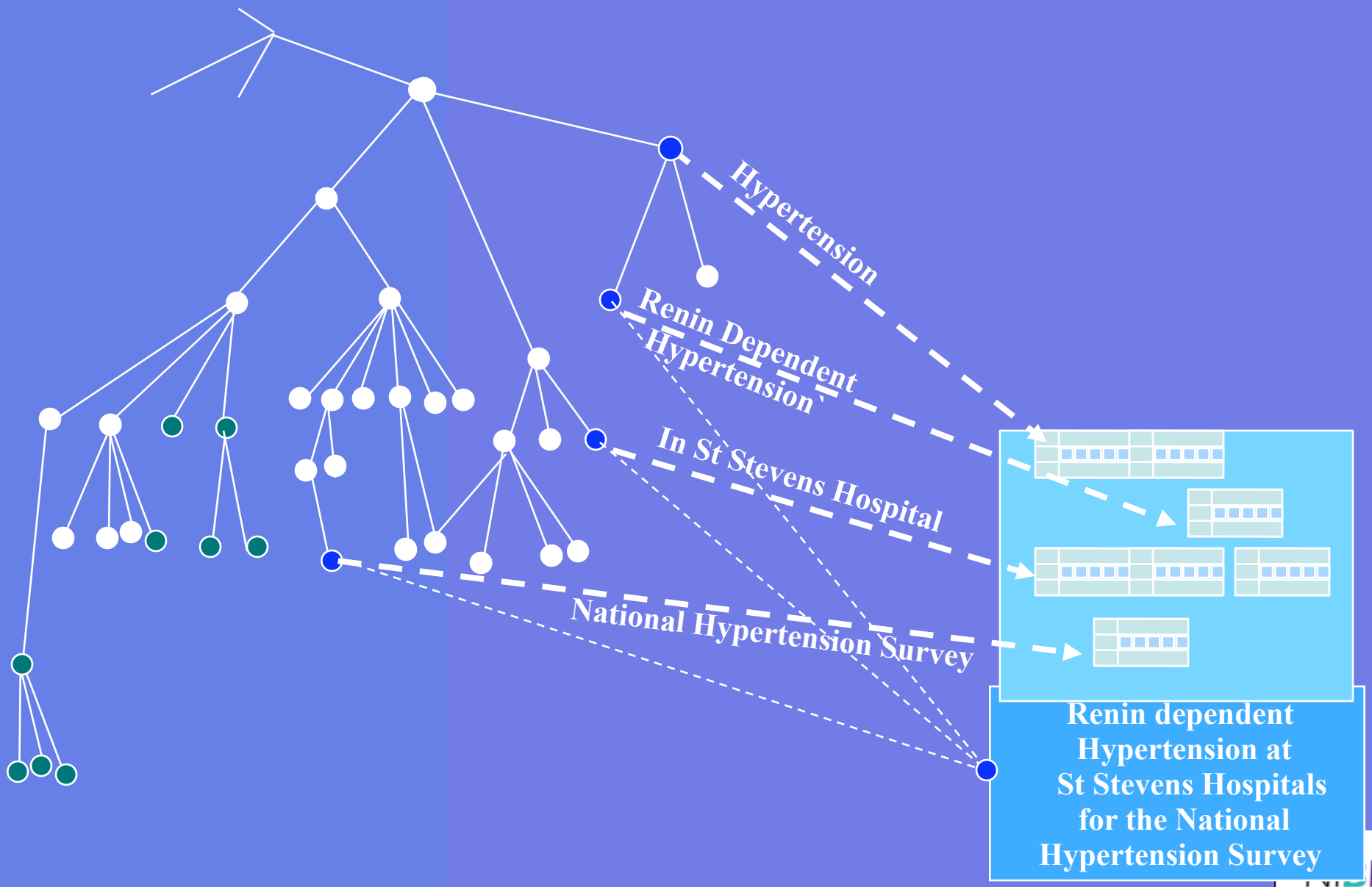
But there are combinatorially many possible forms

- The PROMIS system was discontinued in 1987 at 70K forms and accelerating
  - A major influence on our work
    - For us KR is a way to avoid combinatorial explosions
- A supplier recently expanded all XML forms for data capture in one clinic to 10^7

Fractal tailoring of reusable resources:

example of data collection forms for trials



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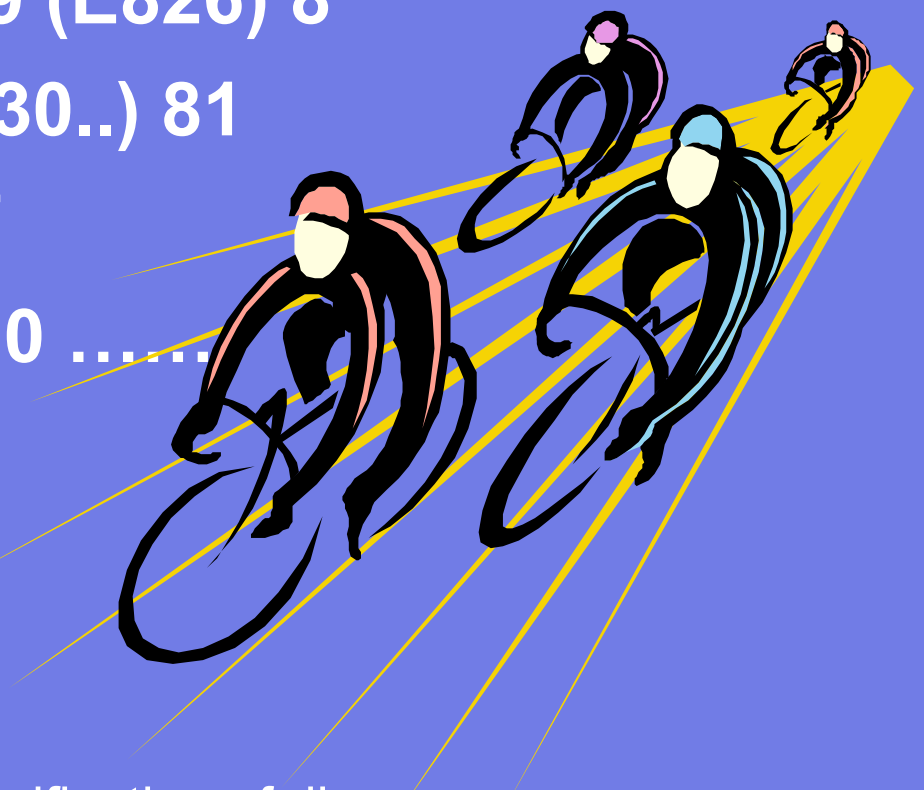
Problems:

The exploding bicycle

(codes for injuries involving cyclists)

- 1972 ICD-9 (E826) 8
- READ-2 (T30..) 81
- READ-3 87
- 1999 ICD-10 ……



ICD = International Classification of diseases

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1999 ICD10: 587 codes

- V31.22 Occupant of three-wheeled motor vehicle injured in collision with pedal cycle, person on outside of vehicle, nontraffic accident, while working for income
- W65.40 Drowning and submersion while in bath-tub, street and highway, while engaged in sports activity
- X35.44 Victim of volcanic eruption, street and highway, while resting, sleeping, eating or engaging in other vital activities

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Building large Terminologies Logic for "Conceptual Lego"

hand

extremity

body

chronic

acute

abnormal

normal

ischaemic

deletion

polymorphism

mucus

gene

protein

polysacharide

cell

expression

Lung

infection

inflammation

bacterium

virus

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Logic as the clips for "Conceptual Lego"

"***SNPolymorphism*** of ***CFTRGene*** causing ***Defect in MembraneTransport*** of ***Chloride Ion*** causing ***Increase*** in ***Viscosity*** of ***Mucus*** in ***CysticFibrosis***…"

"***Hand*** which is ***anatomically normal***"

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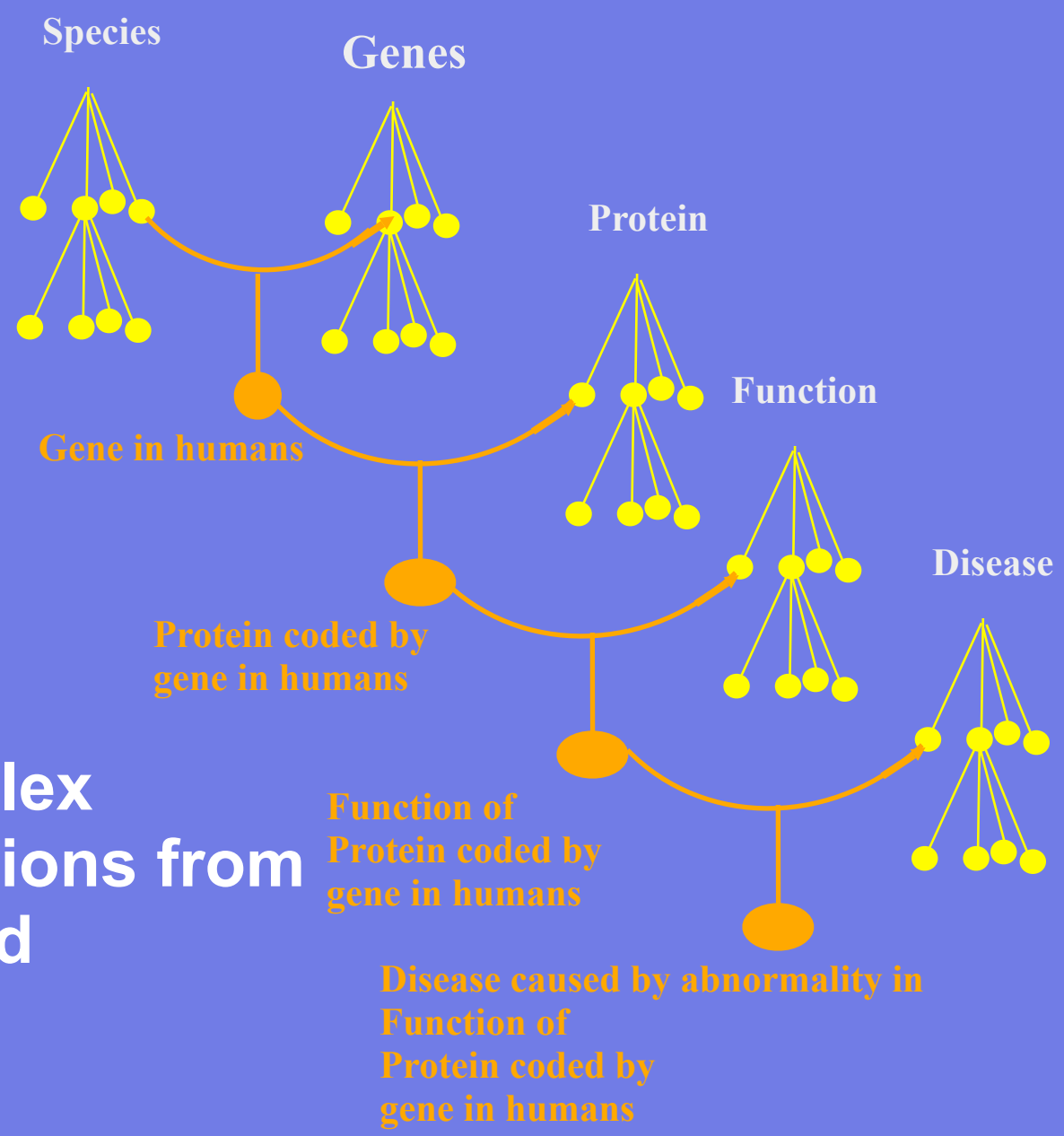
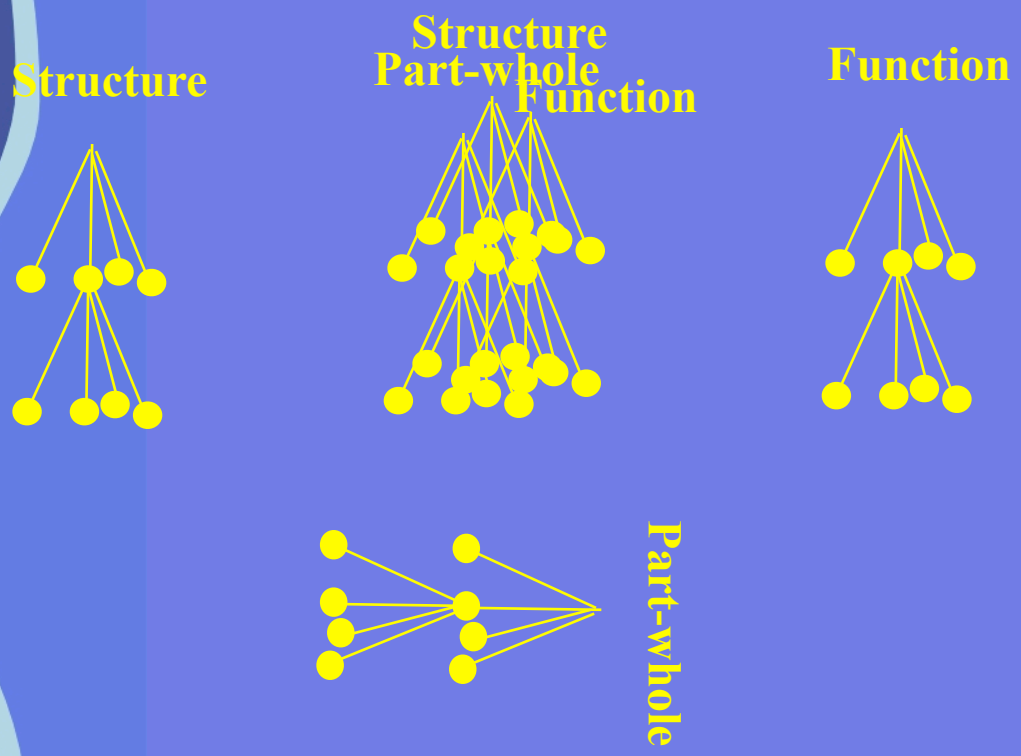


Build complex representations from modularised primitives

Normalising (untangling) Ontologies



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Untangling and Enrichment

Using a classifier to make life easier

Substance
- Protein
- - ProteinHormone
- - - Insulin
- - Enzyme
- - - ATPase
- Steroid
- - SteroidHomone^
- - - Cortisol
-Hormone
- - ProteinHormone^
- - - Insulin^
- - SteroidHormone^
- - - Cortisol^
- Catalyst
- - Enzyme^
- - - ATPase^

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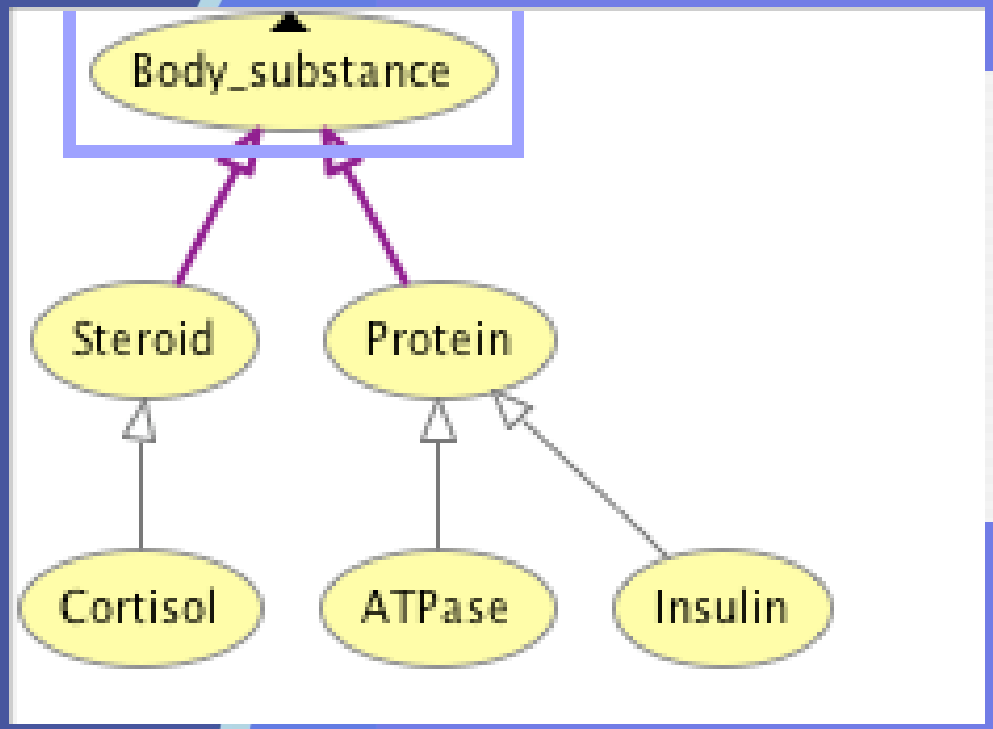
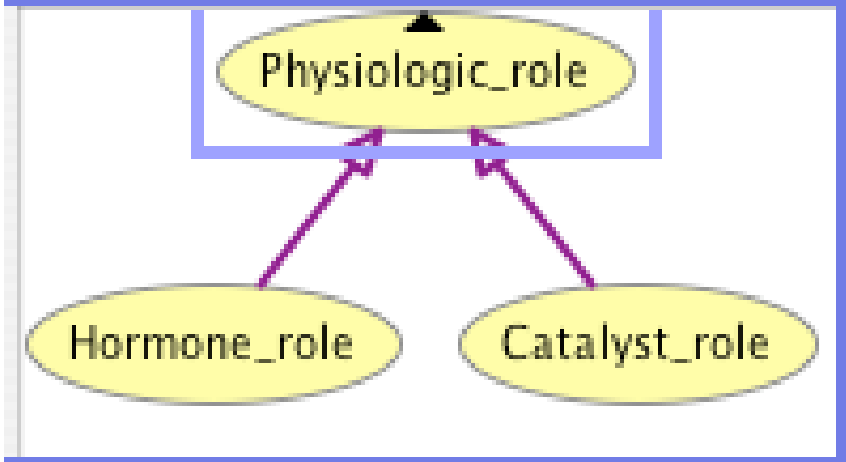
Modularised into structure and function ontologies (all primitive)





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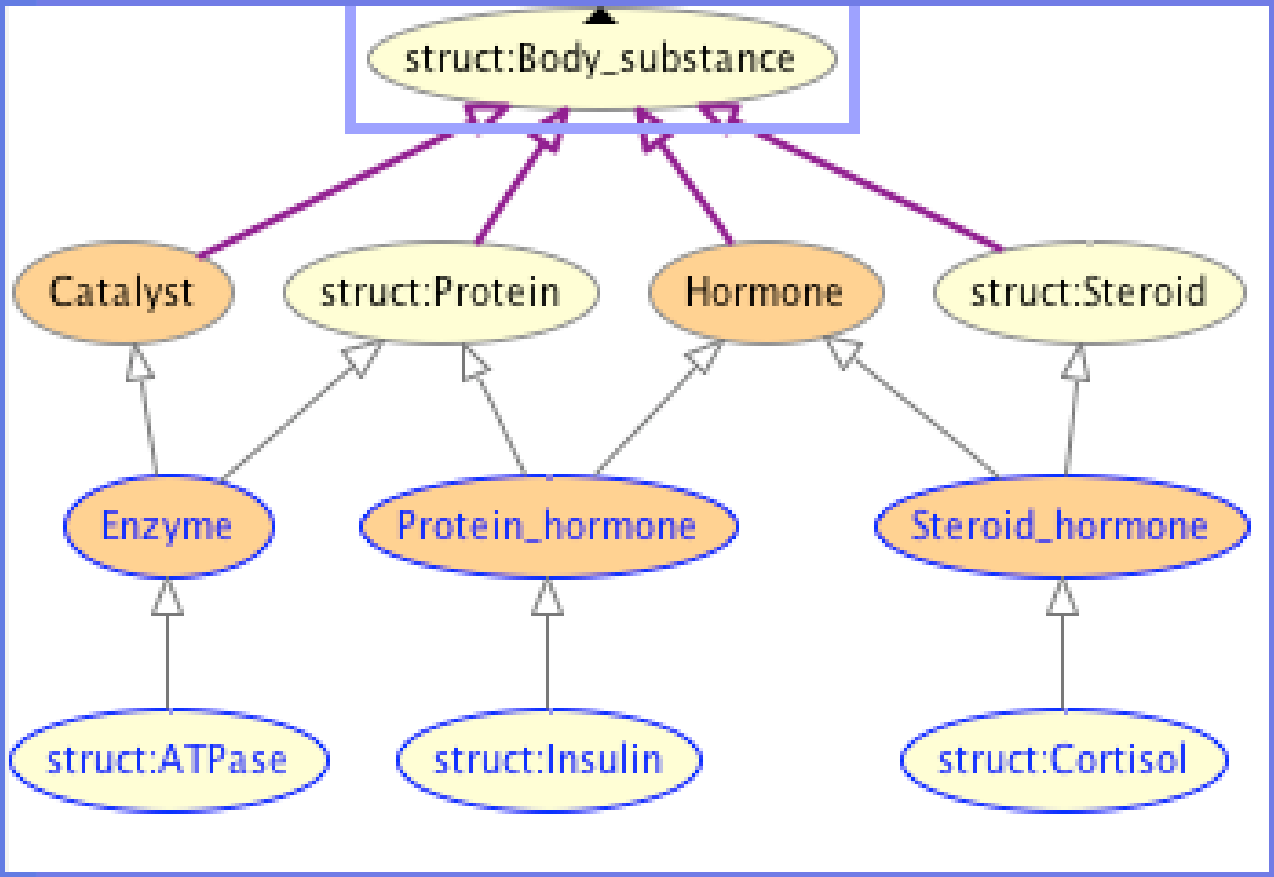
Unified ontology after classification



Ontology normalisation: Enforced modularity

- All primitives form disjoint trees
- All polyhierarchies formed by inference from definitions
  - No arbitrary subclass axioms
- Therefore
  - All concepts have most specific primitive ancestor
  - No disjunctions in domain and range constraints
- Consequences
  - Changes occur in exactly one place
  - Defeasible inheritance can be constrained so that each property inherited only along one taxonomy
    - The same property cannot apply from two different sources that unless one subsumes the other

Led almost by accident to methods for Integrating multiple big vocabularies

- + ' Vascular surgery'
- ' Vascular repair'
  - + ' Arterial repair'
  - - ' Venous repair'
    - - 'READ X00yA Repair of pulmonary vein'
      - x 'READ 790F1 Repair of partial anomalous pulmon
      - - 'READ 79050 Correction of total anomalous pulmo
        - x 'NCSP FFG Transponering av totalt anomalt m
        - x 'NCSP FFG00 Reparation vid suprakardiell TA
        - x 'NCSP FFG20 Reparation vid infrakardiell TAP
        - x 'NCSP FFG30 Reparation vid blandad TAPVD
    - + 'READ X00yX Repair of systemic venous pathway'
    - x 'READ XE0Fj Repair of acquired arteriovenous fistula'
    - + 'NCSP PHC Sutur av ven'
    - x 'NCSP FFJ Interatrial korrektion av systemvenöst blodflöde'
    - + "USE V201 Hémostase d'un accès vasculaire artério-veineux par suture ou par patch"
  - x 'NCSP PWA Reoperation p g a av sårruptur'
  - x ' V432 Suture latérale de la veine cave inférieure sus-hépatique ou des veines sus-hépatiques'

- + surgery of blood vessel
- repair of blood vessel
  - + repair of artery
  - - repair of vein
    - - repair of pulmonary vein
      - x repair of partial anomalous pulmonary venous connection
      - - repair of total anomalous pulmonary venous connection
        - x repair of total anomalous pulmonary venous connection with closure
        - x repair of total anomalous pulmonary venous connection to Brachioce
        - x repair of total anomalous pulmonary venous connection to blood ve
        - x repair of total anomalous pulmonary venous connection to blood ve
    - + repair of systemic vein

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And to real world problems
The Coding of Chocolate
An international conversion guide

SNOMED-CT	Term	CTV3
C-F0811	Bounty bar	UbOVv
C-F0816	Crème egg	UbOW2
C-F0817	Kit Kat	UbOW3
C-F0819	Mars Bar	UbOW4
C-F081A	Milky Way	UbOW5
C-F081B	Smarties	UbOW6
C-F081C	Twix	UbOW7
C-F0058	Snicker	Ub1pT

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…but logic & formal ontology scare users

- Require months to train even to a minimal level
- People make errors
  - Even experienced people
    - Logic inferences can be directly contrary to language maxims
- Make logic (& formal ontology) the "assembly language"
  - Give users high level languages
    - Ideally built with meta-authoring language construction kit
      - *Use "Intermediate Representations"*

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Intermediate Representations "Close to user forms"

***Before*:**

('SurgicalProcess' which

isMainlyCharacterisedBy (performance which

isEnactmentOf ('SurgicalFixing' which

hasSpecificSubprocess ('SurgicalAccessing'

hasSurgicalOpenClosedness (SurgicalOpenClosedness which

hasAbsoluteState surgicallyOpen))

actsSpecificallyOn (PathologicalBodyStructure which <

involves Bone

hasUniqueAssociatedProcess FracturingProcess

hasSpecificLocation (Collum which

isSpecificSolidDivisionOf (Femur which

hasLeftRightSelector leftSelection))>))))

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Intermediate Representations "Close to user forms"

After:

"Open fixation of a fracture of the neck of the left femur"

- MAIN fixing
  ACTS_ON fracture
    HAS_LOCATION neck of long bone
      IS_PART_OF femur
        HAS_LATERALITY left
  HAS_APPROACH open

"Fixation of fracture of neck of left femur by open approach"

From 3-6 months training
to 3-6 days training

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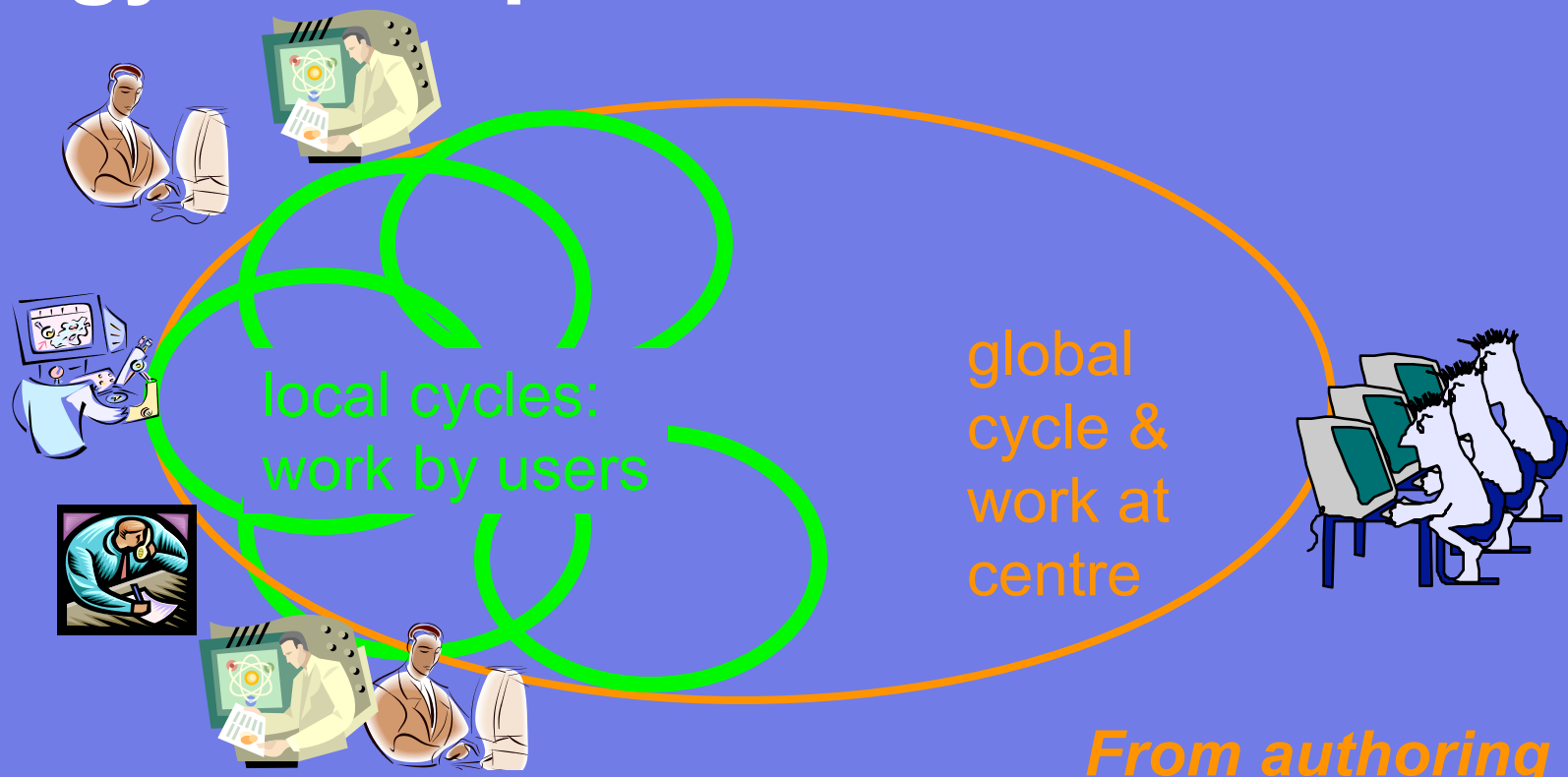
Supports Loosely coupled distributed ontology development



From 80% central/global effort to 10% central/global effort

From authoring to meta-authoring

User effort cut by 75% compared with manual methods
Mostly in reduced committee meetings & arguments

A simple recent example: “Manchester OWL syntax”

- ∃owns.Dog someValuesFrom(owns,Dog) owns SOME Dog
- ∀owns.Dog allValuesFrom(owns,Dog) owns ONLY Dog

Or for one client just:

*	property	min	max	filler
	terms:has_a	0		Dosage
AND	terms:has_a	0		Therapeutic Substance Unit Cl...
AND	terms:has_a	1		Route of administration

Users face a complex landscape

Courtesy of Hodgson, TopQuadran via Carole Goble

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Inhabited by many tribes, Each tribe in its own teepee

Complexity theory

Default logics

KR Logics

Logic programming

Argumentation

Natural Language

Bayesian analysis

Belief Revision

Fuzziness

Description logic

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and what feel like class divides

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The chain of ad hoc envy

Pure Logician/ Mathematician

Too neat
Too academic!
Doesn't understand!

Too scruffy
too ad hoc
Doesn't understand!

KR Researcher

Too neat
Too academic!
Doesn't understand!

Too scruffy
too ad hoc
Doesn't understand!

Knowledge Engineer

Too nea!
Too academic!
Doesn't understand!

Too scruffy
too ad hoc
Doesn't understand!

Application Builder

Too neat
Too academic!
Doesn't understand!

Too scruffy
too ad hoc
Doesn't understand!

No one person can understand it all - must manage the chain

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… but logicians and ontologists are often seen as policemen

Incomplete! Undecidable!
Higher order! No semantics!
Not realistic! Not ontocleaned!

… and seem to insist on solving harder problems than the user actually has

… often without examples of why not

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…or insist users understand the solution space

And don't come back until you have the semantics clear

The opportunity & challenge of knowledge acquisition

Meet users where they are

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Remember: logic is hard & most users are symbolophobes

- How many OWL experts here could get all of the following in the correct subsumption hierarchy first time?
  - p some A
  - p some ASub
  - pSub some A
  - pSub some ASub
  - p only A
  - p only ASub
  - pSub only A
  - pSub only ASub
  - p exactly 1 A
  - p exactly 1 ASub
  - pSub exactly 1 A
  - pSub exactly 1 ASub

I didn't:
Why I need tools and a classifier

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Matching problems and solutions The science & craft of KA

- Patterns, guidelines and tools
- Reformulations of users' "solutions"
- Collaborations betwee behavioural & domain scientists
- Challenges and demonstrations

Some observations…

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Working with users:
The basics - I hope I am "teaching grandma to suck eggs"

- Do something useful - *First do the right thing!*
- Make it usable
  - Find a champion & early adopters
  - Embrace users' attempts at solution
    - At least it is probably useful
      - an example; a working specification
  - Watch, ask, listen, and believe
    - There is no point in arguing with somebody that it is easy
    - There Is no point in arguing with somebody that they understand
    - Get help -
      - Involve behavioural scientists
      - Use language and images - involve linguists
    - Involve the implementers
    - Build for feedback
- Accept that clever things may be useless

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The interesting may not be useful

- Of medical decision support systems in the literature in 1995
  - 70% addressed diagnosis
- Success rate of evaluated medical decision support systems in the literature in 1995
  - Alarms 75%
  - Treatment Management 65%
  - Diagnosis 17%

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And you can only tell if its useful if you know "What's it for?"

- Tens of Millions spent on SNOMED's 450K codes
  - Only 10K have ever been used
    - Many applications find 50%-75% missing
- Hard to predict users' needs
  - So build it "just in time" if possible
  - And based on evidence
    - Mine the web
    - Mine corpora
    - Observe users
    - Build in feedback

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Some arguments only have answers wrt problems

- **Open vs closed world reasoning**
  - **Querying Rail Timetable:**
    "Is there a train from Podebrady that gets me to Prague tonight?"
    - **"No"**
      - Possibly false, but useful
        - » I can't get better information
    - **"Might be"**
      - True but not useful & possibly misleading
  - **Querying FoaF**
    "Does Alan have any friends?"
    - **"Don't know"**
      - At least not misleading
    - **"No"**
      - Wrong (I hope)

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…which emphasizes again that: Metaknowledge is knowledge

- The railway timetable is presumed complete
  - But how do I know?
    - Do I trust the resource to tell me or depend on my experience?
- Biographies in FoaF are probably incomplete
  - But how do I know?
    - What about some other data somewhere on the Semantic Web?
- *Need some new metadata standards urgently*

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Get the user's to own it

- The Gene Ontology is the most successful "ontology"/ "thesaurus"
  - Not rigorous; many faults
  - But owned by the biologists and does *their* job
- The Gene Ontology Next Generation project accepts and delivers in their format
  - The OWL is just another quality assurance tool

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QA with users: The Logical answer isn't always the right answer

"Cardiovascular Disorder" → "Disorder or injury of Heart or blood vessel"

"Slashed wrist" → "Self inflicted laceration of radial artery"

The user is right - fix the axioms:

"Cardiovascular Disorder" → "Disorder or injury of Heart or Great Vessels or arterial system as a whole"

…but may have to deal with differences in logic and language

- **Logically:**
  Four limbed animals do not subsume four legged animals
  - **unless we represent explicitly our background knowledge that four legged animals have no other limbs**
    - **but we never say it**
    - **how to convey the intuitions to users?**

Expressivity is more important than constraints

- Draw all the inference the user expects from "sensible" premises
  - Users won't mind if wrong inferences could have been drawn from nonsense premises
    - Provided the nonsense premises can't get in by accident

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Find a way to do it: nonstandard reasoning: Commonalities and differences

- Classify all the proteins with phosphatase[1] activities
  - Identify all the features in common
    - Simple subgraph algorithm
  - Create the generic abstraction
  - Classify again to find more phosphatases
    - 20 new phosphatases
      - Some probably implicated in disease
  - Classify by which tissue they come from
    - Repeat
      - Try to understand why some tissues suffer from disease and some don't

[1]"Phosphate-ase" - enzyme that breaks down phosphate bonds; the primary source of energy in cells; can drive super-oxidation; prime source of damage in diabetes, extreme inflammation in Intensive Care Units, atherosclerosis, and probably much else

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Hide formalisms
Focus on meta-modelling

- Make the logic the assembly language
  - Build "compiler compilers" for close to user forms
    - Ought to be a major focus of our research
  - Transformations, import, export
- Support implementors and localisers
  - Tools to build user oriented special purpose tools, languages and interfaces
- Build quick tools for common patterns
  - Tabbed outlines for taxonomies
  - Easy visualisation and specification of disjoints
  - Wizards and Patterns for features & value sets
  - Special tools for lists
  - …

Help users to work together

- Science is Cooperative
  E-Science is e-Cooperative
- Supporting cooperation requires new kinds of knowledge
  - Modularisation
  - Dependencies
  - Communication
  - User profiles
  - Views
  - Transforms
  - …

Develop the whole chain of Knowledge Acquisition

Language → informal →Semi-formal → Formal

↙

Language ← informal ←Semi-formal

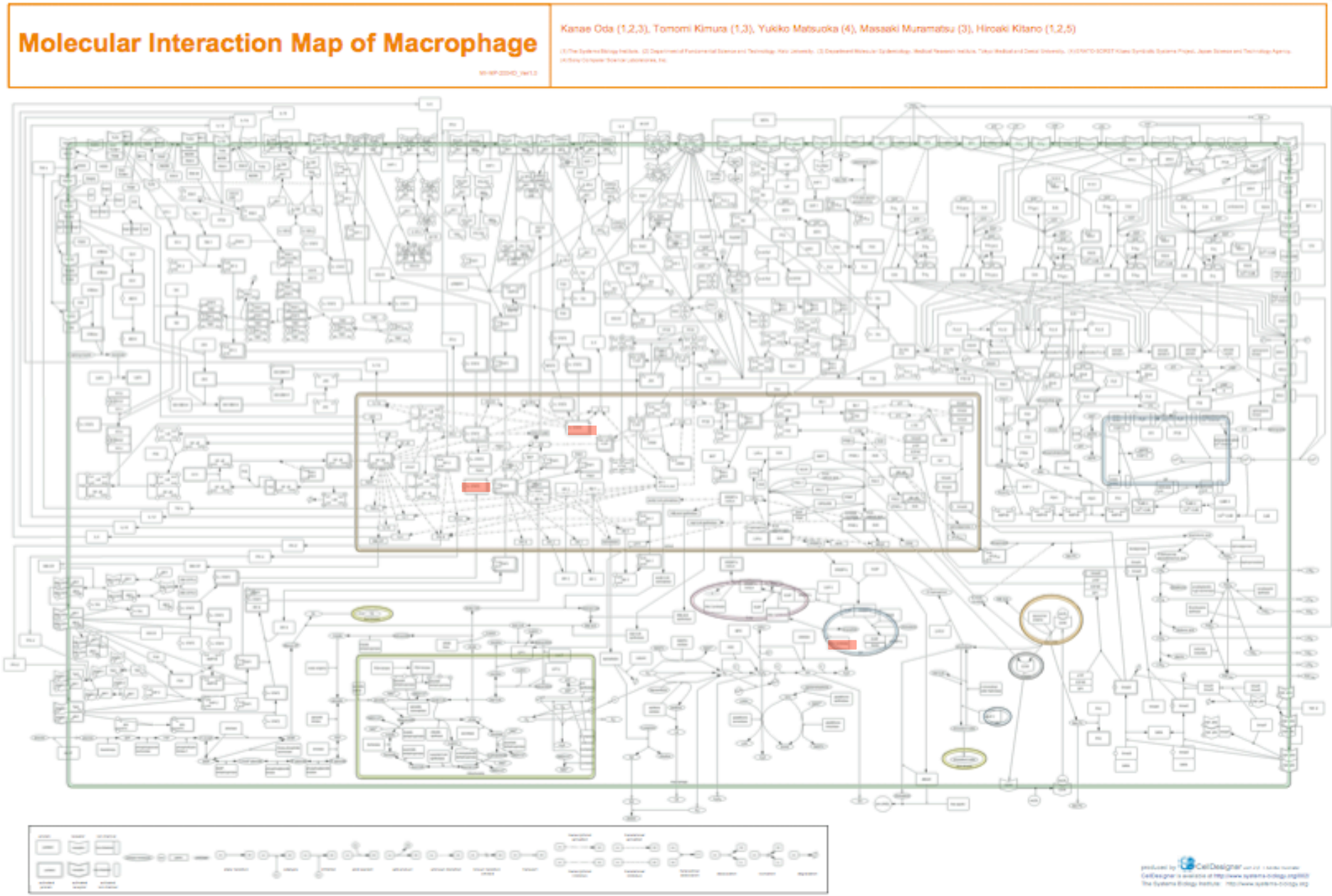
Language Generation (an often forgotten technology)

- Even simple language generation helps
  - Even logicians may find it easier to work in pseudo-natural language
- If not natural language at least intuitive syntax
  - Syntax matters to understanding

Seek evidence

- Use corpora, NLP & the Web
  - Experts often wrong about what really happens
    - Beware of committee views
    - Beware of dogma

Find a sweet spot even if “trivial”



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Prioritize issues to users' requirements -

thank you OWL 1.1

- Role assertions
  - "Fracture of neck of femur" is a kind of "Fracture of Femur"
    - hasLocus o isPartOf →hasLocus
  - Accept repurposing
    - There are alternative solutions for anatomy but essential for other cases
      - "Uncle"
      - "Reified relations" (Ontological "qualities")

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Test at scale

- Many users' problems are BIG
  - Biological examples ≥ 10K concepts
  - Medical examples 20K…500K concepts

Use the tricks of the trade

(especially to reduce arguments)

- "Pericardium" (covering of the heart) & "Heart":
  - To anatomists: they are two different organs
  - To the clinicians: they are parts of the same functional unit
- The role hierarchy can let us support both views

  is_clinical_part_of
  ← is_structural_part_of

…but hide them from (most) users

- Neither the anatomist nor the surgeon need to know about the other
  - In GALEN we had several different variants of the intermediate representation compiler to deal with intractable arguments
    - QA always passed by all

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Make representations maintainable & evolvable
(basic software engineering)

- **Don't be too clever**
  (Avoid "Write once read never")
  - **"Shortest S-Expression for a function"**
    "Maximum code in a C 'for' statement"
  - **"Clever" inference in an OWL KB**
    - **Avoid**
      - Making inferences from domains/range
        - » May better to check before inference
          - * Or do inference in multiple step
      - Complex disjoint axioms and disjunctions
- **Design so all changes made in only one place**
  - **Normalise ontologies**
- **Be systematic - follow patterns**
- **Provide regression testing from the beginning**
  - **Preferably before building**
- **Support debugging**

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Remember: Your part is only one source of error *It will require empirical testing*

- Errors come from
  - Errors & low inter-rater reliability in input
    - Often under 80%
  - Implementation errors in applicxations
  - The perversity of the universe - the Rumsfeld effect

- It is going to require empirical testing
  - The ONLY test that will be accepted for most applications is empirical
    - Whether or not the algorithms are complete

NIBHI

My top next priority for OWL: "What is it sensible…

- To ask
  - Everything is permitted unless it is forbidden
    - Natural open world logical view
      - Sets of constraints
- To tell (sanctioning)
  - Everything is forbidden unless it is permitted
    - Natural frames/OO/UML view
      - Sets of templates

- It is sensible to ask about "Green entities"
  - There are entities that are green
    - It is not sensible to ask about "Green dreams"
      - No: dreams have no colour
    - *The more I know the less it is sensible to ask*
- Is it sensible to tell that balls are green?
  - If it might sensibly be green
    - *The more I know, the more it is sensible to tell*
      - A hard/impossible notion to capture in first order theories

But the basis for intelligent user interfaces

Needed by *every* user we have encountered

Related: "Optional"

- What are the semantics of :
  - *0..n* in UML?
  - or *canonical graphs* in Conceptual Graphs?
  - or *sensible sanctions* in GRAIL?
  - or *slot attachment* in Frames?
  - or *minCardinality(0)* in OWL?
- Supported by every formalism any user will ever have used
  - There must be something to it
    - Even if it isn't first order
- Needed by every data application we have encountered

Related but different: "May"

- **May**
  - **"What *may* cause pneumonia?" What classes of bacteria *may* cause pneumonia?**
    - **Hard to express in DLs/OWL**
      - Need richer relations amongst properties
        - » causes → may_cause
          Almost captures it
        - » "Anything that acts has the potential to act"
          "Anything that does not have the potential to act, cannot act"
          …is there additional semantics?
        - » Very messy without special tools and operators in user language

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… others needs for a better match to biomedical knowledge

- **Prototypical knowledge**
  The heart is generally on the left but sometimes on the right
  - **Normative solutions OK for some things**
    - **"The normal hand has five digits"**
    - **"The normal heart is on the left"**
  - **Simple explicit exceptions OK for some things**
    - **"All human cells have nuclei except red blood cells"**
  - **But otherwise need prototypical knowledge & exceptions**
    - **"Typically birds fly"**
    - **"Typically gram positive bacteria are penicillin sensitive"**
- Uncertainty - another step? a different formalism?
  - 70% of appendices are in right lower abdomen
    - Can fuzziness/probability/… be contained in the same framework or do we need a true hybrid system?
      - **Needs to link to utilities and decision theory**

Summary: Help fill the gap

Problem space

Watch, ask, listen to, & believe users

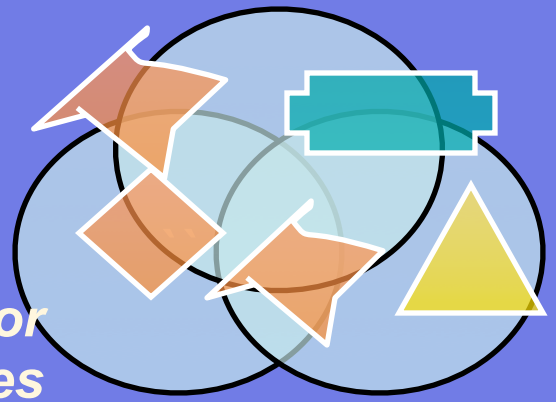
embrace users' partial solutions as requirements

Guidelines, Patterns, Tools, Modularity,Views, Environments
metadata, work arounds, hybrid systems, …

Design for modularity, maintenance & evolution

Support meta users & application builders

Solution space



Fit solutions to problems

Look to user requirements for implementation priorities