
TRUST
Team for Research in Ubiquitous Secure Technology

# *TRUST*: Team for Research in Ubiquitous Secure Technology

## Understanding the Challenges with Medical Data Segmentation

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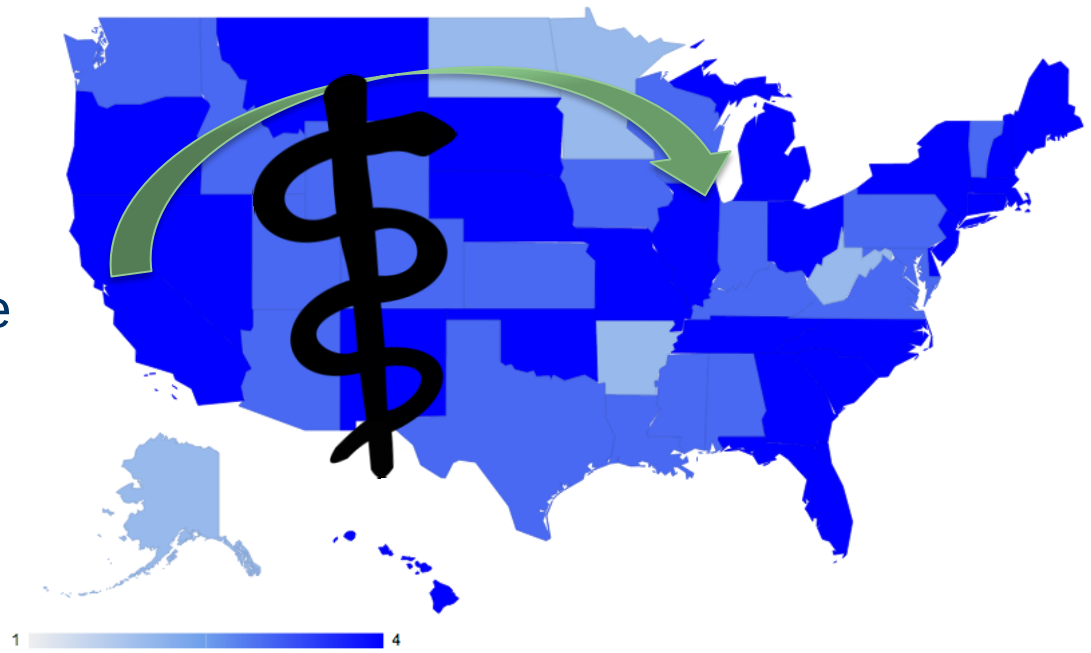
San José State UNIVERSITY · STANFORD UNIVERSITY · VANDERBILT UNIVERSITY

# Health Information Exchange (HIE)



- Federal
  - HIPAA
  - HITECH
- State laws on
  - Mental Health
  - Substance Abuse
  - STDs
  - Genetic testing
- Organizational




Health Information Exchange Cloud

# Compliance approaches

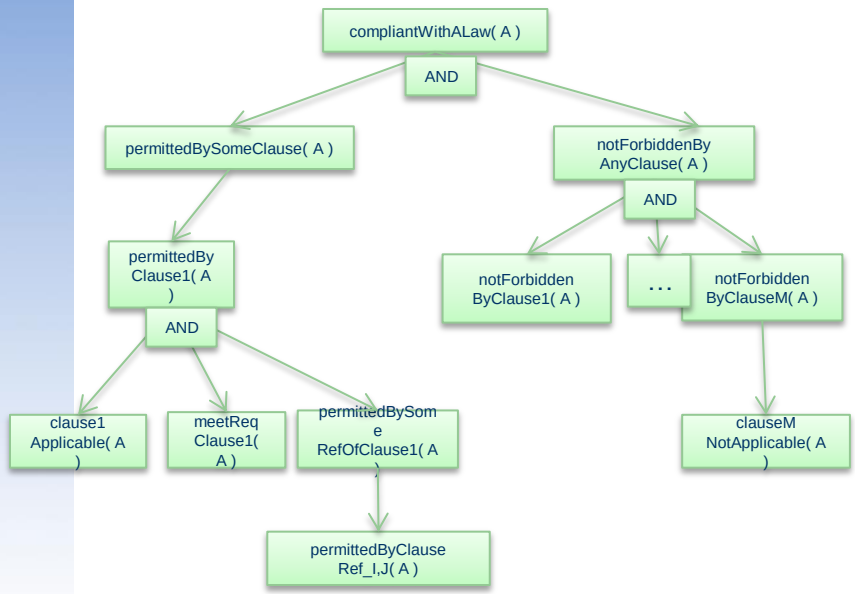
## Automated Policy

**HIPAA Law**

§ 164.502 Uses and disclosures of protected health information: general rules.
(a) Standard. A covered entity may not use or disclose protected health information, except as permitted or required by this subpart or by subpart C of part 160 of this subchapter.
(1) Permitted uses and disclosures. A covered entity is permitted to use or disclose protected health information as follows:
(i) To the individual;
(ii) For treatment, payment, or health care operations, as permitted by and in compliance with §164.506;
(iii) Incident to a use or disclosure otherwise permitted or required by this subpart, provided that the covered entity has complied with the applicable requirements of §164.502(b), §164.514(d), and §164.530(c) with respect to such otherwise permitted

```
>|
%%Standard rules for "uses and disclosures"
permitted_by_164_502_a(A) :-
  is_from_coveredEntity(A),
  is_phi(A),
  (permitted_by_160_C(A);
  permitted_by_164_502_a_1(A);
  required_by_164_502_a_2(A)).

permitted_by_164_502_a_1(A):-
  permitted_by_164_502_a_1_i(A);
  permitted_by_164_502_a_1_ii(A);
  permitted_by_164_502_a_1_iii(A);
  permitted_by_164_502_a_1_iv(A);
  permitted_by_164_502_a_1_v(A);
  permitted_by_164_502_a_1_vi(A).
```




IHI 2012

# Data segmentation

**Health Record**

- Medications
- Previous diagnoses
- Labs

Sensitive conditions

*According to research by the California HealthCare Foundation, 15 percent of patients who know their information will be shared would hide information from their doctor, and another 33 percent would consider hiding information[1].*

# Automated Policy



## HIPAA Law

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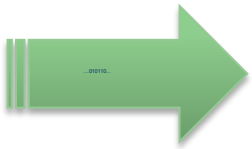

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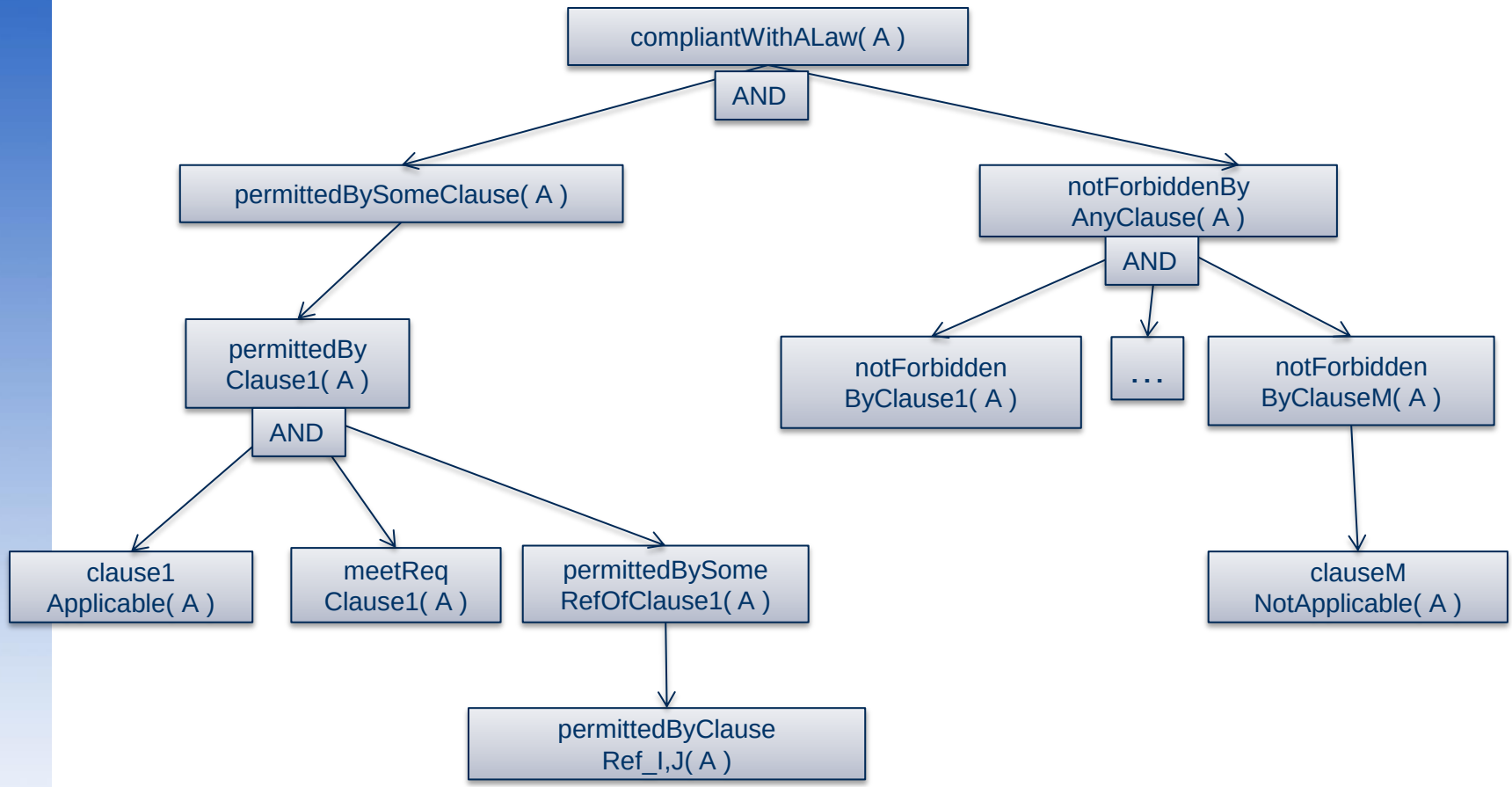
permitted_by_164_502_a_1(A):-
  permitted_by_164_502_a_1_i(A);
  permitted_by_164_502_a_1_ii(A);
  permitted_by_164_502_a_1_iii(A);
  permitted_by_164_502_a_1_iv(A);
  permitted_by_164_502_a_1_v(A);
  permitted_by_164_502_a_1_vi(A).
```

- HIPAA law translated into a logic program
- Finite Models
- Acyclic

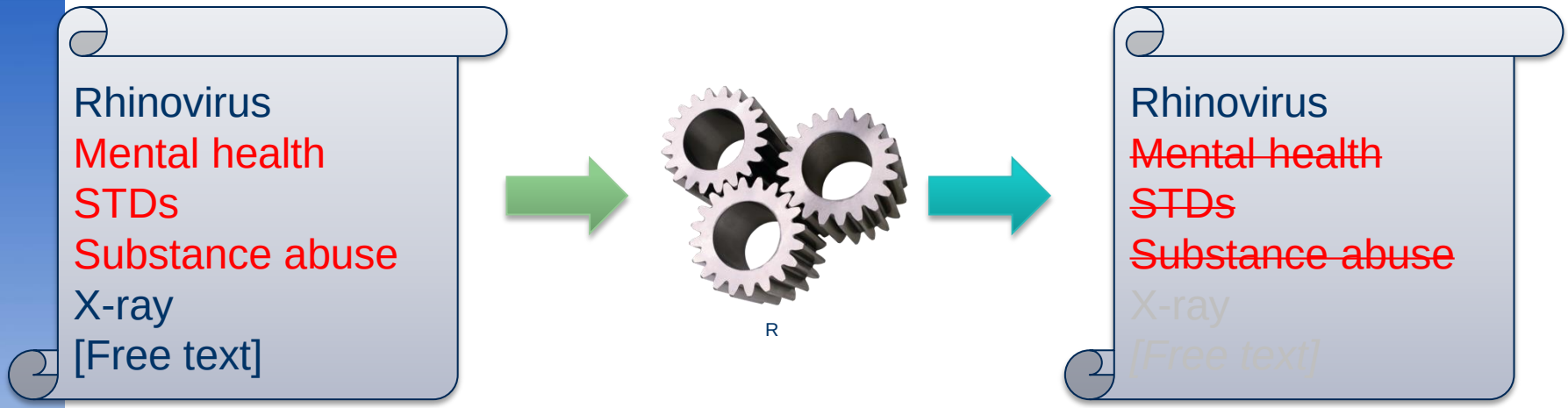
# Compliance Trees





# Data segmentation






- Remove sensitive codes
- Codes hard to identify
- Second-order effects of segmentation on decision making

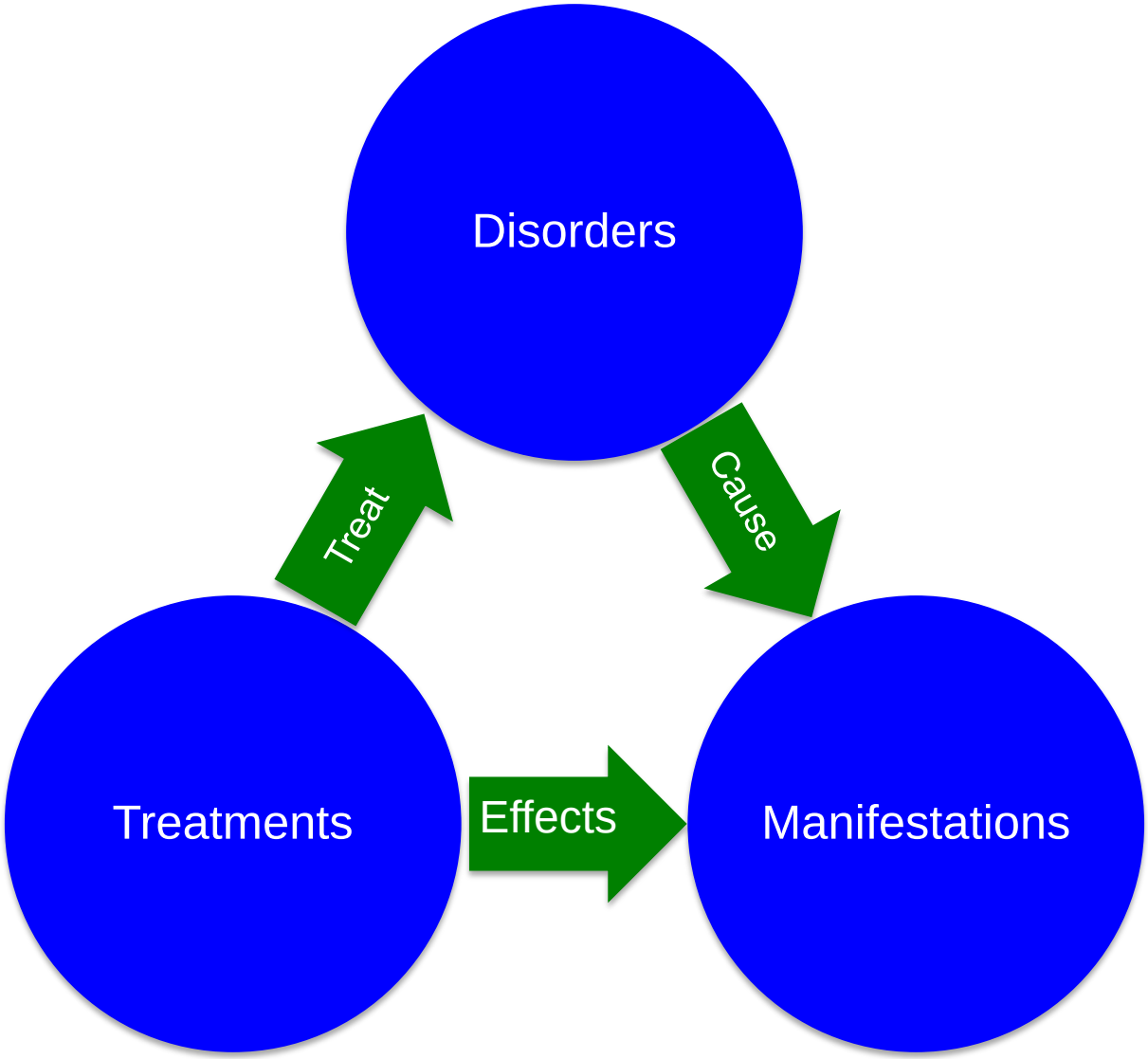
# Threat Model

- Attacker has direct access to redacted health record, medical literature
- Attacker does not have the computational capability to circumvent security mechanisms that protect the primary sensitive codes

# Example: AIDS



- 0th-order: ICD-9 code 42
- 1st-order: Treatments & defining conditions
  - Kaposi's Sarcoma
  - Antiretrovirals
  - Proposed Drug-drug interaction checkers, Fixed-Dose Combination Drugs
- 2nd-order: non-specific disease
  - "Toxoplasmosis" AND "Hepatitis B" AND "Encephalopathy" AND "Progressive multifocal leukoencephalopathy" AND "Cryptococcosis"
- Another ex: Rett syndrome
  - wringing constipation female


Disorders
Treat
Cause
Treatments
Effects
Manifestations

# Treatments

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| Concept | Description | Links | Notes |
|---|---|---|---|
| Risperidone | Treats schizophrenia, bipolar disorder, and autism. | schizophrenia, bipolar disorder, autism, weight gain, insomnia, alopecia | Use of Risperidone usually implies treatment of a mental health disorder. |
| Carbamazepine | Anti-convulsant and mood-stabilizing drug. Treats epilepsy and bipolar disorder. | epilepsy, bipolar disorder, headaches, drowsiness | Primarily used to treat mental health disorders. Could be used off-label to treat Complex regional pain syndrome(ICD9: 337.21) |
| Citalopram | Primarily used as an SSRI to treat depression. Can also be used to treat hot flashes. | depression, hot flashes, anorgasmia, nausea, diarrhea | Can treat both sensitive and non-sensitive conditions. |
| Lamotrigine | Primarily used as an anticonvulsant drug to treat epilepsy and bipolar disorder. Can also treat migraines. | epilepsy, bipolar disorder, migraines | Can be used to treat mental health disorders or migraines. |

# Example

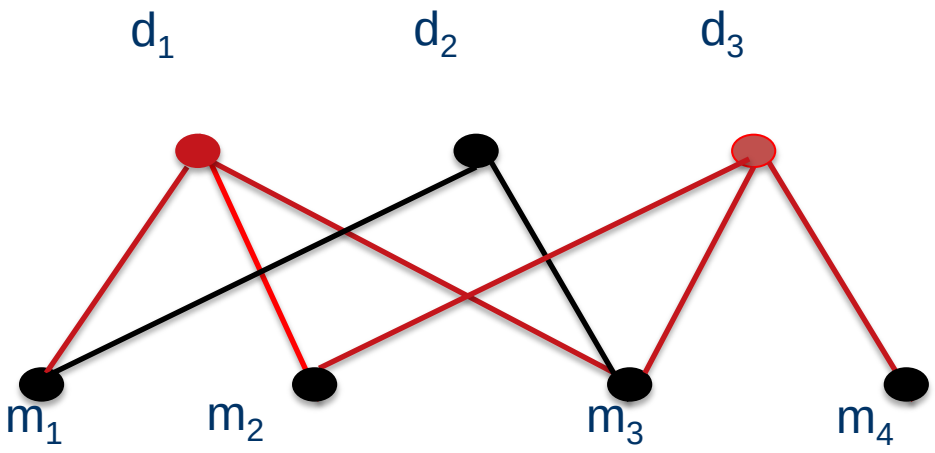


| Hypothesis |
| --- |
| $\{d_1, d_3\}$ |
| $\{d_2, d_3\}$ |
| $\{d_1, d_2, d_3\}$ |
| $\{d_1, d_2\}$ |

**D**

**C**

**M**




Reggia's set cover model

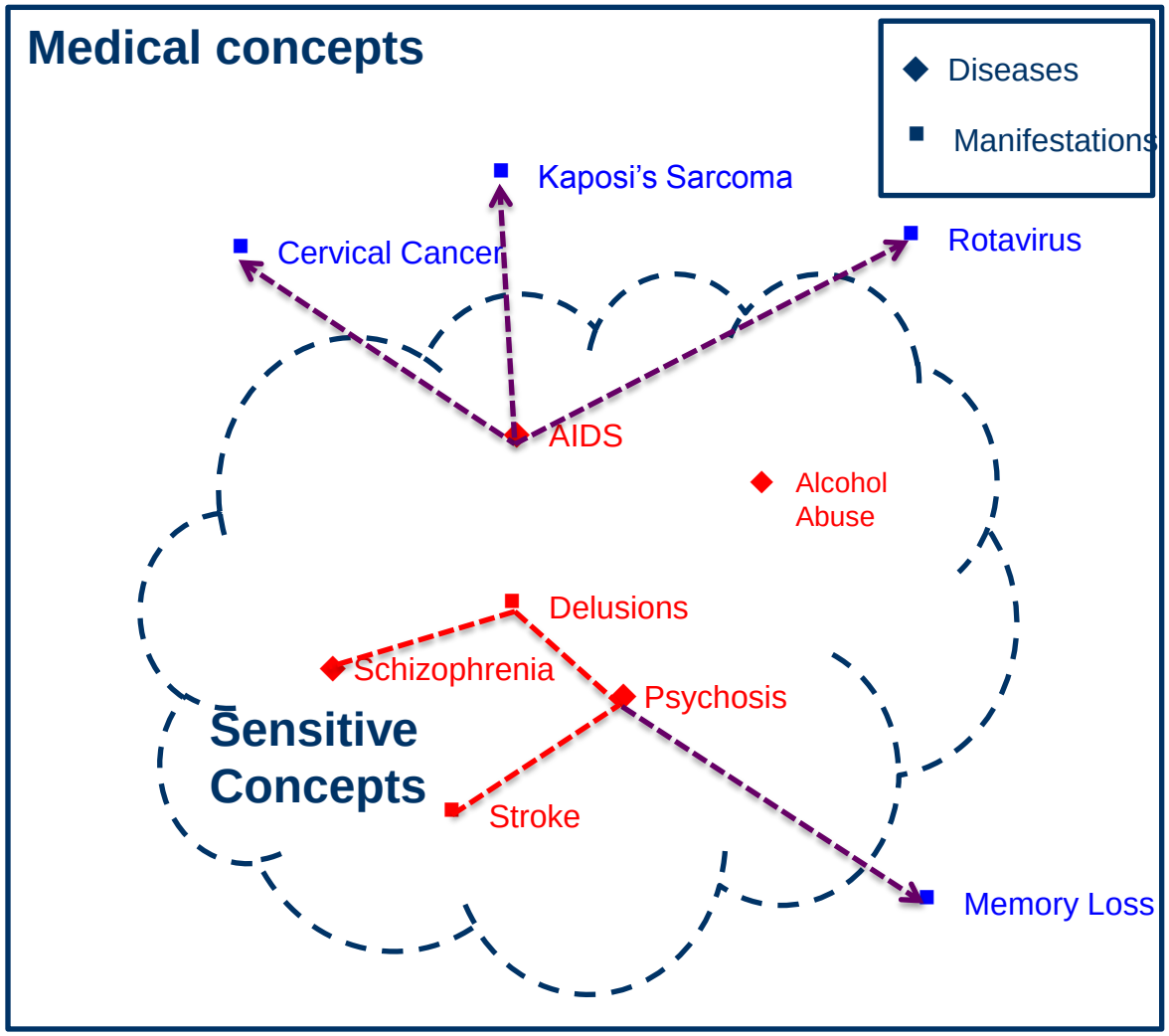
- Plausibility – set cover
- Likelihood – Occam's razor and fitness

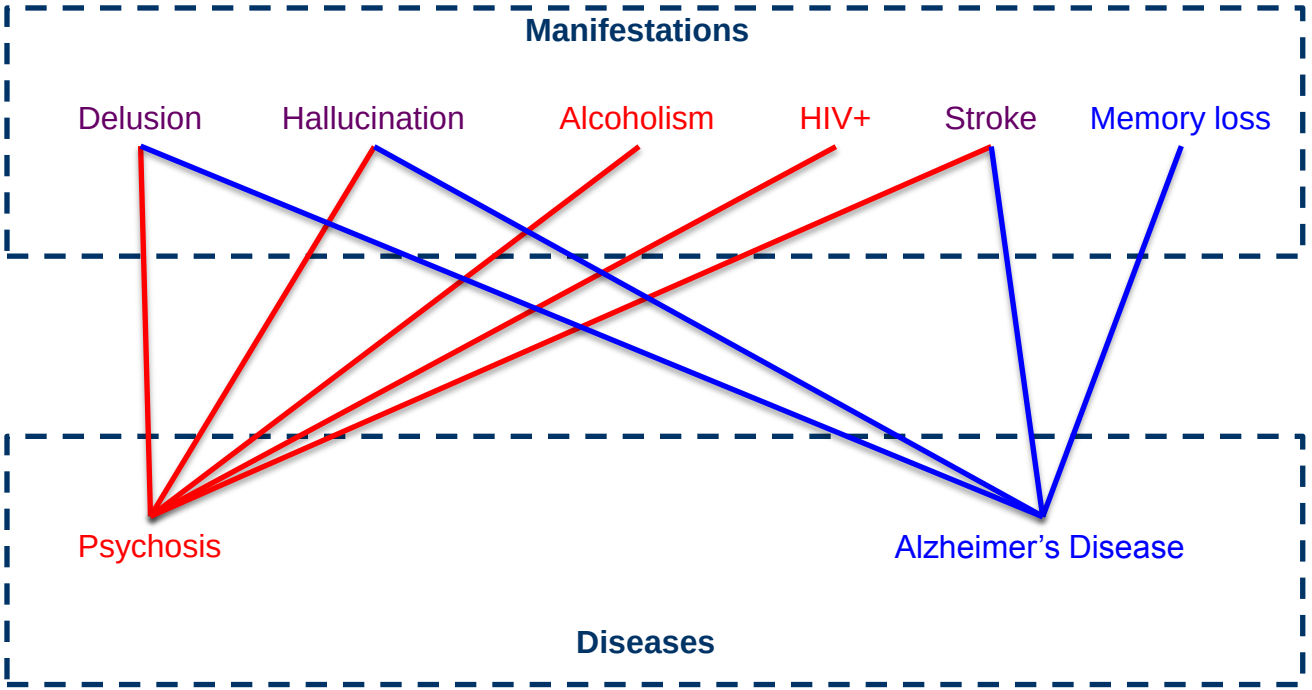
# Explanation of manifestations



- Best explanation E of manifestations:
  - Covers all observed manifestations M+
  - Is the simplest (parsimonious) definition

- Heuristics for "best cover"
  - Minimality - |E| is minimal
  - Criticism: minimal cardinality covers can be too restrictive
    - Occam's razor vs Hickam's dictum
  - Irredundancy – removing any disorder results in a non-cover of M+
  - Relevancy – Every *d* in D must be causally associated with some *m* in M+


Medical concepts
Diseases
Manifestations
Kaposi's Sarcoma
Cervical Cancer
Rotavirus
AIDS
Alcohol Abuse
Delusions
Schizophrenia
Psychosis
Sensitive Concepts
Stroke
Memory Loss



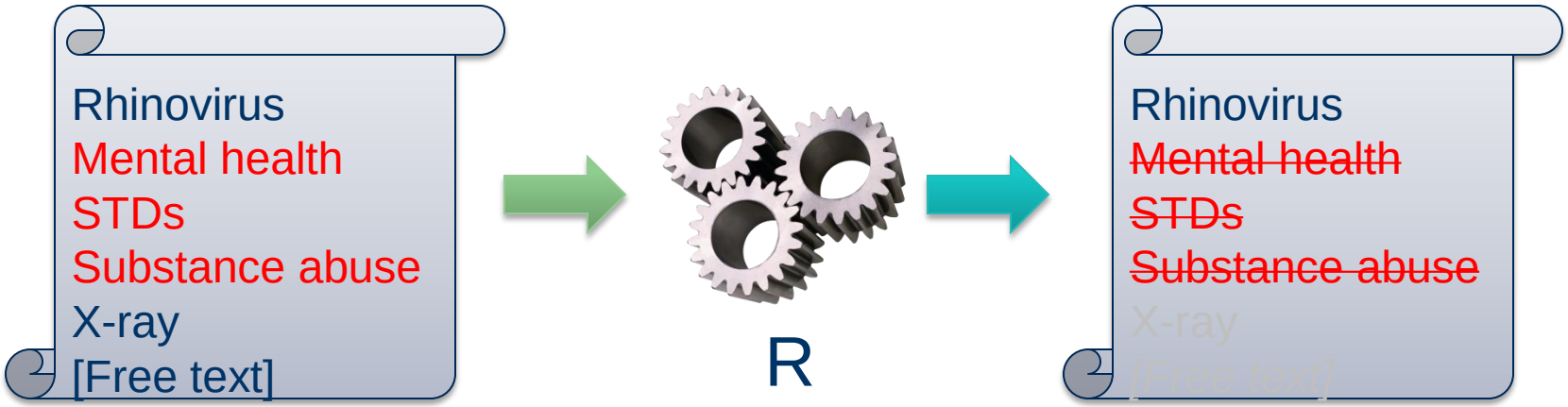

Source: PubMed, NIH.gov

# Predicate-Reducer definition



A – Medical algorithm
π – Policy determines sensitive code s
M – Medical record
Predicate P(M, π) – Determines if s ï M
Reducer R(M, π) – Removes s from M

Ideal reducer $A(m) = A(R_p(m)) \text{ " } m \hat{I} M$



# Inference approach



Input: Reduce(Diseases U Manifestations U Treatments)

Output: Inferred Diseases

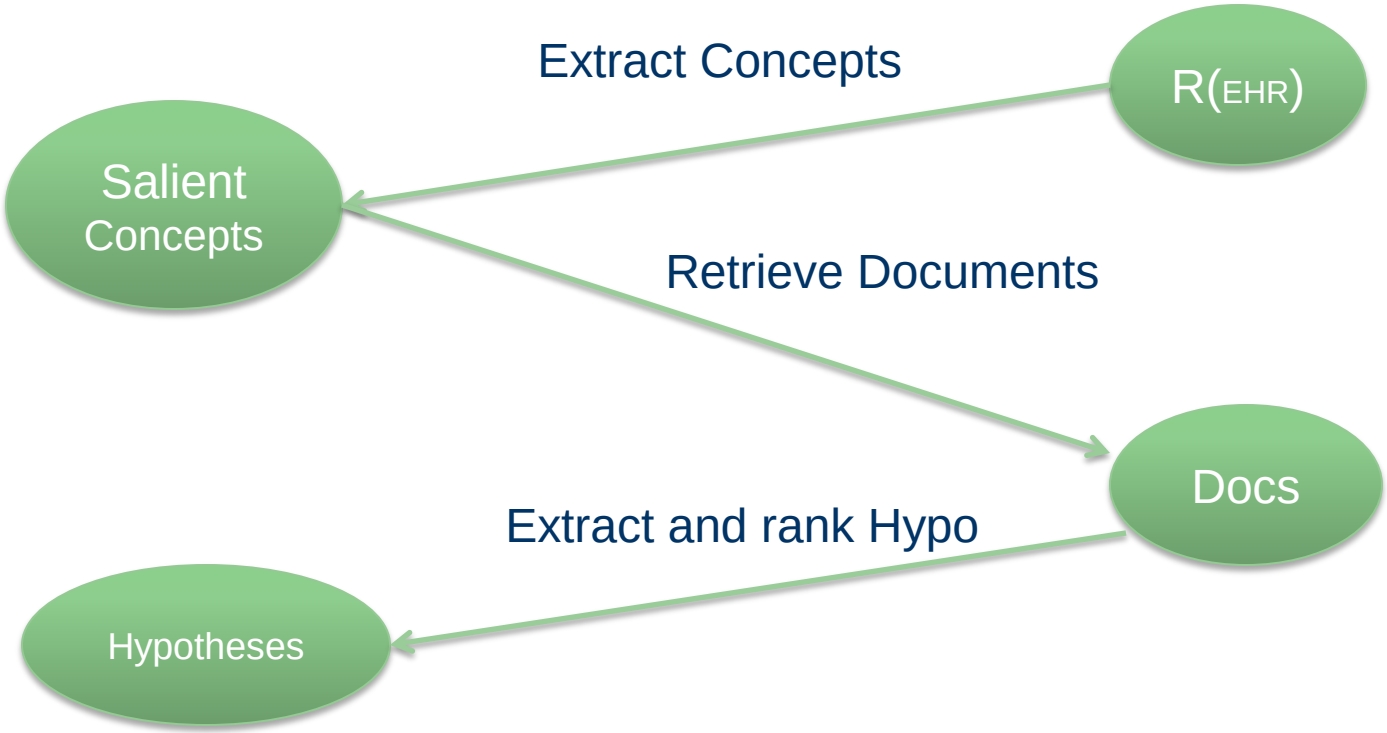
1. For each input, evoke hypotheses
2. Evaluate hypotheses
3. Rank hypotheses according to fitness

Hypothesis fitness

- Competing hypotheses, e.g. $d_1$ or $d_2$

# Algorithm overview





# Algorithm overview



```
hypotheses ← ∅;
for i = 1 → numIters do
    query ← ∅;
    for j = 1 → numTerms do
        /* select a concept from the EHR using
           a probability distribution                    */
        x ← select_concept(concept_probs, EHR)
        query ← query ⋃ x;
    end
    /* search for docs that contain the query
       terms                                             */
    sr ← search(query, knowledge_base) ;
    /* Identifies hypotheses from medical
       concepts in documents                             */
    hypotheses ← update_hyp(hypotheses, sr);
    /* Evaluates hypotheses according to
       plausibility criteria                             */
    results ← eval_hypotheses(hypotheses) ⋃ results;
end
rank(results);
```

**Algorithm 1:** Inference algorithm

# Concept Support Index



**Concept Support Index**

Let $H \subseteq W$ be a set of concepts representing a hypothesis that the patient has had the medical manifestations, diseases, and treatments in $H$. Let $h \in H$ be a particular concept in $H$, then the Concept Support Index with respect to a medical knowledge document $doc$ is defined as:

$$CSI(h, doc) = \frac{Count(h, doc)}{\sum_{w \in W} Count(w, doc)} \quad (1)$$

$$CSI(H, doc) = \sum_{h \in H} CSI(h, doc) \cdot w_h \quad (2)$$

, where $w_h \in [0, 1]$, $\sum_{h \in H} w_h = 1$, and $Count(h, doc)$ counts the number of occurrences of $h$ in $doc$.

# Hypothesis Fitness Index



$$HFI(H, Docs) = \sum_{doc \in Docs} CSI(H, doc) \cdot weight(doc, H) \tag{3}$$

where $weight(H, doc)$ is a weighting function. One such function could be BM25 [20, 30, 34], which is defined as

$$\text{BM25}(D, Q) = \sum_{q_i \in Q} \text{IDF}(q_i) \cdot \frac{f(q_i, D) \cdot (k_1 + 1)}{f(q_i, D) + k_1 \cdot (1 - b + b \cdot \frac{|D|}{\text{avgdl}})}, \tag{4}$$

where

$$\text{IDF}(q_i) = \log \frac{N - n(q_i) + 0.5}{n(q_i) + 0.5}, \tag{5}$$

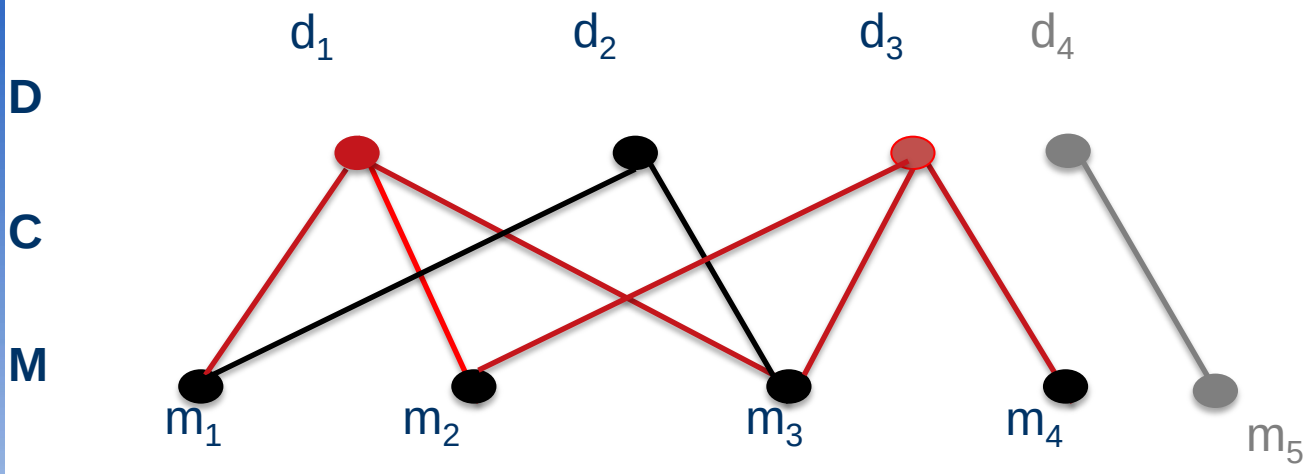
$f(q_i, D)$ is the term frequency of $q_i$ in $D$, $k_1 \in \mathbb{R}^+$, $b \in [0, 1]$, and $avgdl$ is the average document length of $Docs$.

# Results

| Condition | Query | Results | Medical codes | Notes |
|---|---|---|---|---|
| Rett Syndrome | “wringing” AND “female” AND “constipation” AND ”scoliosis” | 3 articles suggest Rett Syndrome. | F84.2, R09.0, K59.0, 737.0 | Pubmed |
| Rett Syndrome | “wringing” AND “female” AND “constipation” AND ”scoliosis” | 1.73M results, 5 of top 10 results suggest Rett Syndrome, including NIH Medline. | F84.2, R09.0, K59.0, 737.0 | Google |
| AIDS | "Toxoplasmosis" AND "Hepatitis B" AND "Encephalopathy" AND "Progressive multifocal leukoencephalopathy" AND "Cryptococcosis” | 140,000 results. 5 of top 10 suggest AIDS. | 130, 070.2, 348.30, 046.3, 117.5 | Google |
| AIDS | ... | 18,000 results. >8 of top 10 suggest AIDS. | 130, 070.2, 348.30, 046.3, 117.5 | Bing |

# Possible defenses






- Deniability through relative strengths of hypotheses
  - Hide non-sensitive EHR as well
  - Enhance competing hypothesis, e.g. Citalopram
  - Introduce noise (controversial)

# Questions?

# Ask your doctor!