Overview of Clinical Care

HST.956/6.S897
Machine Learning in Healthcare
February 7, 2019

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Outline

• Goals of Health Care
  • Mortality
  • Disability
  • Morbidity
• Tasks of Health Care
  • Diagnosis
  • Prognosis
  • Treatment
  • Prevention/Public Health
• Paying for Health Care
Goals of Medicine: (1) Cure the sick
Goals of Medicine: (1) Cure the sick
WHO Constitution defines “health”

“a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”

- Physical
- Mental
- Social
  - very hard to measure
Life Expectancy of the World Population in 1800, 1950 and 2012

Countries are ordered along the x-axis ascending by the life expectancy of the population. Data for almost all countries is shown in this chart, but not all data points are labelled with the country name.

Data source: The data on life expectancy by country and population by country are taken from Gapminder.org.
The interactive data visualisation is available at OurWorldinData.org. There you find the raw data and more visualisations on this topic.

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Longevity at birth

<table>
<thead>
<tr>
<th>Country</th>
<th>Male 2018</th>
<th>Male 2001</th>
<th>Female 2018</th>
<th>Female 2001</th>
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<tbody>
<tr>
<td>Rwanda</td>
<td>62.6</td>
<td>38.35</td>
<td>66.5</td>
<td>39.65</td>
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<td>47.64</td>
<td>65.6</td>
<td>48.56</td>
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<tr>
<td>Kenya</td>
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<td>46.57</td>
<td>66.1</td>
<td>48.44</td>
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<td>Cambodia</td>
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<td>54.62</td>
<td>67.9</td>
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<td>62.12</td>
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<td>70.7</td>
<td>58.96</td>
<td>78.0</td>
<td>67.73</td>
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<td>72.9</td>
<td>68.89</td>
<td>77.7</td>
<td>73.71</td>
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<td>Albania</td>
<td>76.0</td>
<td>69.01</td>
<td>81.6</td>
<td>74.87</td>
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<td>76.69</td>
<td>84.7</td>
<td>80.84</td>
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<td>USA</td>
<td>77.8</td>
<td>74.37</td>
<td>82.3</td>
<td>80.05</td>
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<td>France</td>
<td>78.9</td>
<td>75.01</td>
<td>85.3</td>
<td>83.01</td>
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<td>Japan</td>
<td>82.2</td>
<td>77.62</td>
<td>89.0</td>
<td>84.15</td>
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</table>
Share of persons surviving to successive ages for persons born 1851 to 2031, England and Wales according to mortality rates experienced or projected, (on a cohort basis)

Data source: Office for National Statistics (ONS). Note: Life expectancy figures are not available for the UK before 1951; for long historic trends England and Wales data are used. The interactive data visualization is available at OurWorldInData.org. There you find the raw data and more visualizations on this topic.
Distribution of Death Rates by Age

- Life table deaths by year (Japan, 2015)

http://www.ipss.go.jp/p-toukei/JMD/00/STATS/Mx_1x1.txt
Ethnic Differences

Figure 6. Life expectancy at birth, by sex, race and Hispanic origin: United States, 1975–2015

- **White female**
- **Black female**
- **White male**
- **Black male**

**2015**

- **Male**
  - Hispanic or Latino: 79.3
  - White, not Hispanic: 76.3
  - Black, not Hispanic: 71.8

- **Female**
  - Hispanic or Latino: 84.3
  - White, not Hispanic: 81.1
  - Black, not Hispanic: 78.1
Causes of death
(USA, 2014)

<table>
<thead>
<tr>
<th>Cause</th>
<th>Deaths/100K</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>192.7</td>
<td>23.4</td>
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<tr>
<td>Cancer</td>
<td>185.6</td>
<td>22.5</td>
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<tr>
<td>Chronic lower respiratory disease</td>
<td>46.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Accidents</td>
<td>42.7</td>
<td>5.2</td>
</tr>
<tr>
<td>Stroke</td>
<td>41.7</td>
<td>5.1</td>
</tr>
<tr>
<td>Alzheimer's disease</td>
<td>29.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Diabetes</td>
<td>24.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Influenza and pneumonia</td>
<td>17.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Kidney disease</td>
<td>15.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Suicide</td>
<td>13.4</td>
<td>1.6</td>
</tr>
<tr>
<td>OTHER</td>
<td>215.8</td>
<td>26.2</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>823.7</strong></td>
<td><strong>100.0</strong></td>
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Morbidity: Top 10 Chronic Conditions
Persons aged ≥ 65

<table>
<thead>
<tr>
<th>Condition</th>
<th>Both</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arthritis</td>
<td>49.6</td>
<td>40.7</td>
<td>55.7</td>
</tr>
<tr>
<td>Hypertension</td>
<td>39.0</td>
<td>33.0</td>
<td>43.2</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>30.0</td>
<td>35.2</td>
<td>26.3</td>
</tr>
<tr>
<td>Heart disease</td>
<td>25.7</td>
<td>26.9</td>
<td>24.9</td>
</tr>
<tr>
<td>Orthostatic impairment</td>
<td>16.8</td>
<td>15.7</td>
<td>17.8</td>
</tr>
<tr>
<td>Cataracts</td>
<td>15.5</td>
<td>11.3</td>
<td>18.4</td>
</tr>
<tr>
<td>Chronic sinusitis</td>
<td>15.2</td>
<td>13.7</td>
<td>16.2</td>
</tr>
<tr>
<td>Visual impairment</td>
<td>10.1</td>
<td>12.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Genitourinary</td>
<td>9.9</td>
<td>11.3</td>
<td>8.9</td>
</tr>
<tr>
<td>Diabetes</td>
<td>8.9</td>
<td>7.8</td>
<td>9.7</td>
</tr>
</tbody>
</table>

## Next 10 Chronic Conditions

Persons aged ≥ 65

<table>
<thead>
<tr>
<th>Condition</th>
<th>Both</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varicose veins</td>
<td>7.7</td>
<td>3.4</td>
<td>10.8</td>
</tr>
<tr>
<td>Hernia</td>
<td>7.6</td>
<td>9.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Hemorrhoids</td>
<td>7.6</td>
<td>7.1</td>
<td>8.0</td>
</tr>
<tr>
<td>Psoriasis, dermatitis, dry skin</td>
<td>7.4</td>
<td>6.3</td>
<td>8.3</td>
</tr>
<tr>
<td>Hardening of arteries</td>
<td>7.4</td>
<td>7.3</td>
<td>7.4</td>
</tr>
<tr>
<td>Tinnitus</td>
<td>7.3</td>
<td>7.6</td>
<td>7.1</td>
</tr>
<tr>
<td>Corns, calluses &amp; bunions</td>
<td>7.3</td>
<td>4.2</td>
<td>12.7</td>
</tr>
<tr>
<td>Constipation</td>
<td>6.5</td>
<td>4.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Hay fever</td>
<td>6.4</td>
<td>6.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Cerebrovascular</td>
<td>5.7</td>
<td>5.6</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Quality of life

Value of a total life depends on

• Length (assume now is N)
• Quality (q) over time
• Discounts (g) for future or past
  • depends very much on what the value is to be used for
  • what is an appropriate discount factor?

\[ V_N = \int_{t=0}^{T} q(t)g(t - N)dt \]
Activities of Daily Living

**Basic**
- Bathing and Showering
- Personal hygiene and grooming
  - brushing/combing/styling hair
- Dressing
- Toilet hygiene
- Functional mobility ("transferring")
  - walk, get in and out of bed
  - get into and out of a chair
- Self-feeding (not including cooking or chewing and swallowing)

**Instrumental**
- Cleaning and maintaining the house
- Managing money
- Moving within the community
- Preparing meals
- Shopping for groceries and necessities
- Taking prescribed medications
- Using the telephone or other form of communication
Goals of “Occupational Therapy”

- Care of others (including selecting and supervising caregivers)
- Care of pets
- Child rearing
- Communication management
- Community mobility
- Financial management
- Health management and maintenance
- Home establishment and maintenance
- Meal preparation and cleanup
- Religious observances
- Safety procedures and emergency responses
- Shopping
Mortality, Disability, Morbidity

(A) 1980 Female Mortality, Hypothetical Disability and Morbidity

US Female 1980

(B) As (A), but with mortality reduced to 20% of actual
implies Epidemic of chronic illness & mental disease

(C) Compression of Morbidity

(D) Life Span Extension
As (B), but proportional reduction in morbidity and disability
Societal quality of life

• Aggregation of individual qualities
  + Equity (distributions)

• Is more better? (Population control)
• Is less better?
• How much to spend?
Time scale in medicine

- Cure—usually acute illness
- Manage—long-term, chronic illness
- Prevent
- Predict
Outline

• Goals of Health Care
  • Mortality
  • Disability
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• Tasks of Health Care
  • Diagnosis
  • Prognosis
  • Treatment
  • Prevention/Public Health

• Paying for Health Care
Traditional tasks of medicine

• Diagnosis
  • “the art or act of identifying a disease from its signs and symptoms”
• Prognosis
  • “the prospect of recovery as anticipated from the usual course of disease or peculiarities of the case”
• Therapy
  • “therapeutic medical treatment of impairment, injury, disease, or disorder”
The Medical Cycle

- **initial presentation**
- **examine**
- **data**
- **interpret**
- **information**
- **determine**
- **therapy**
- **plan**
- **diagnosis**

Diagram showing the cycle between initial presentation, examine, data, interpret, information, determine, therapy, plan, and diagnosis.
Care Processes

• Data:
  • observation, instrumentation, monitoring, telemetry, lab tests
• Information:
  • interpretation, filtering, sampling, smoothing, clustering
• Diagnosis:
  • inference, model-based reasoning, classification
• Prognosis:
  • prediction, natural course, experience
• Therapy:
  • planning, predicting effects, anticipating
Cognitive Theory of Diagnosis

• From initial complaints, guess suitable hypothesis
• Use current active hypotheses to guide questioning
• Failure to satisfy expectations is the strongest clue to a better hypothesis; differential diagnosis
• Hypotheses are activated, de-activated, confirmed or rejected based on
  • (1) logical criteria
  • (2) probabilities based on:
    • findings local to hypothesis
    • causal relations to other hypotheses (coherence)

• ≈ Scientific Method

Meta-level processes

• Acquisition and application of knowledge
• Education
• Quality control and process improvement
• Cost containment
• Reference (library)
Enterprise-level Clinical Process Automation…

figure from David Margulies
The “Learning Health Care System”

- Model
- Analyze
- Observe/Measure

- Process
- Medical content
The science of Learning Health Systems: Foundations for a new journal

Charles P. Friedman¹ | Nancy J. Allee² | Brendan C. Delaney³ | Allen J. Flynn⁴ | Jonathan C. Silverstein⁵ | Kevin Sullivan⁶ | Kathleen A. Young¹

¹ Department of Learning Health Sciences, Medical School, University of Michigan, Ann Arbor, Michigan
² Taubman Health Sciences Library, University Library and Department of Learning Health Sciences, Medical School, University of Michigan, Ann Arbor, Michigan
³ Medical Informatics and Decision Making, Imperial College, London, UK
⁴ Medical Informatics, Tempus and Kanter Health Foundation, Chicago, Illinois
⁵ Department of Computer Science, School of Engineering and Applied Science, University of Virginia, Charlottesville, Virginia
How Does the Health System Learn?

• “Evidence-Based Medicine”
  • Contrast with “Tradition-Based Medicine” — Apprenticeship
• Randomized Controlled Clinical Trial (RCT)
  • E.g., is drug A more effective than drug B for condition X?
  • Narrow selection of patient cases and controls
  • Careful collection of systematically organized data
  • Statistical analysis of outcomes
    => Statistically significant conclusions
• But:
  • **Heterogeneity:** Most cases to which RCT results are applied do not fit trial criteria
  • **Short Follow-Up:** Trials run for limited times, but use is longer
  • **Small Samples:** Some effects are rare but devastating
“The Learning Health Care System”

- “one in which progress in science, informatics, and care culture align to generate new knowledge as an ongoing, natural by-product of the care experience, and seamlessly refine and deliver best practices for continuous improvement in health and health care” — IOM

- Needs not currently met:
  - Comprehensive collation of all clinical, social, demographic, behavioral, ... data that are now captured in the health care system
  - Routine capture of novel data sources:
    - genomes, gene expression, etc.
    - environmental factors (e.g., metagenomics)
    - physiological response to life situations
      - (related to fitness and wellness)
  - Technical infrastructure
    - Storage and analysis of truly “big data”
  - Incentives and demonstrations of utility
Use All Possible Data

Prediction = f(inputs)
Goals of Medicine: (2) Keep people healthy

- Public Health
  - Tracking disease prevalence
  - Tracing infections
  - Quarantine
Tracking disease prevalence by systematic classification

• 17th century: John Graunt on the London Bills of Mortality estimated mortality before age 6 at 36%
• 18th century: Sauvage, Linnaeus, Cullen made first attempts at systemic classification
• 1853—first International Statistical Congress led to Wm. Farr’s system:
  • epidemic diseases
  • constitutional (general) diseases
  • local diseases arranged according to anatomical site
  • developmental diseases
  • diseases that are the direct result of violence
  (Note: pre-Pasteur)
• 1890s—Bertillon (Paris) classification: 161 titles, abstracted to 99, and 44
• 1920 International List of Causes of Death
• 1975—ICD-9
• 2015—ICD-10
• ICD-\(n\) are under control of the World Health Organization (WHO)

• ICD-9CM, ICD-10CM are US “Clinical Modifications”, mainly to support billing

https://www.who.int/classifications/icd/en/HistoryOfICD.pdf
Centers for Disease Control and Prevention (CDC)

• Today, we collect death certificates that record direct & indirect causes of death
• Insurance payments are based on classifications of disease, severity, tests, intervention, …

![Death Certificate Image](https://www.cdc.gov/nchs/ppt/nchs2012/li-14_minino.pdf)

- Cerebral hemorrhage
- Nephritis
- Cirrhosis of liver
Cholera, John Snow, and the Broad Street Pump (1854)

- “germ-contaminated water was the source of cholera"
- Localization via mapping
- Led to sanitation improvements
- Snow also used:
  - Double-blind experimental technique
  - Voronoi diagrams to outline neighborhoods closest to each pump

https://upload.wikimedia.org/wikipedia/commons/2/27/Snow-cholera-map-1.jpg
Quarantine

• Isolation separates sick people with a contagious disease from people who are not sick.

• Quarantine separates and restricts the movement of people who were exposed to a contagious disease to see if they become sick.

• Mostly used at ports of entry, but sometimes to try to prevent epidemics
  • Ellis Island
  • “Typhoid Mary”
  • AIDS
  • Ebola
"TYPHOID MARY"

The Extraordinary Predicament of Mary Mallon, a Prisoner on New York's Quarantine Hospital

It is probable that Mary Mallon is a prisoner for life—yet she has committed no crime, has never been convicted of an immoral or wicked act, and has never been a prisoner in any court, nor has she been sentenced to imprisonment by any judge.

Mary Mallon is a cook by profession. She has served in the kitchens of many New York millionaires with entire satisfaction for many years.

Mary Mallon for more than two years has been a prisoner on New York's quarantine island. This, with the unfortunate who are from time to time removed to this isolated spot because they are suffering from smallpox, scarlet fever or other contagious disease.

But while Mary sees these unfortunate victims of various diseases come and go on the hospital ward in due time, she never returns to their homes and friends—Mary stays on forever. There is probably in the whole wide world no prisoner that can furnish a parallel to the extreme misfortune which has brought Mary Mallon to North Brother Island.

Though no fault of hers, Mary Mallon is a living incubator of typhoid fever germs. Every day for two years the officials of the New York Board of Health have examined Mary, and they have been discouraged to find a plentiful supply of new typhoid fever bacilli constantly made each twenty-four hours by Mary Mallon. Mary Mallon, in the five years before authorities put their hands on her, may have caused twenty-six cases of typhoid fever among others. So far as is known, the only means the doctors have had to deal with the disease, and is not now sick.

But somewhere is her anatomy, perhaps in the gall bladder, there is a never failing source of typhoid fever germs. To the physicians of Health Mary has been an incubus for seven years. They are unable to trace her history...
HELMS CALLS FOR AIDS QUARANTINE ON POSITIVE TESTS

By United Press International
CHICAGO TRIBUNE

JUNE 16, 1987  |  WASHINGTON

A quarantine of people who test positive for AIDS infection is the way to halt the spread of the deadly disease, Sen. Jesse Helms (R., N.C) said Sunday. Helms appeared on the CBS "Face The Nation" program after Education Secretary William Bennett, who suggested that prison inmates infected with the AIDS virus should be kept in custody after serving their sentences if they threaten to spread the disease to the general population to take "revenge on society."
Quarantine

• Quarantine is a controversial and debated issue. … significant risks related to human rights, creating fear and confusion…
• Quarantine should be used as a last resort
• Quarantines in urban areas are complicated by the size and density of their populations

• Highly mobile populations make managing and enforcing quarantine more complex
• Large-scale quarantines result in equally large waste disposal needs and other water, sanitation and hygiene vulnerabilities

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Paying for Health Care

• More healthcare than steel in GM cars
• Increased demand
  • Much more possible
  • Better tests, therapies
  • High human motivation
• No pushback
• Waste
  • Unnecessary procedures
    • ½ of health expenses in last year of life
  • Marginally useful procedures
    • Defensive medicine
• Bad Medicine
  • IOM: 48-98K “unnecessary” deaths/year
<table>
<thead>
<tr>
<th>Year</th>
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<th>Belgium</th>
<th>Canada</th>
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<td>2015</td>
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</table>

http://www.oecd.org/health/health-statistics.htm
1970–2017 % GDP spent on health care in various OECD countries
Life expectancy vs. health expenditure, 1970 to 2015

Health financing is reported as the annual per capita health expenditure and is adjusted for inflation and price level differences between countries (measured in 2010 international dollars).

OurWorldInData.org/the-link-between-life-expectancy-and-health-spending-us-focus • CC BY-SA

https://ourworldindata.org/the-link-between-life-expectancy-and-health-spending-us-focus
Standing Still is Not Good Enough

http://theincidentalaleconomist.com/wordpress/the-health-care-productivity-problem/
Less Efficient Sectors Come to Dominate

- Hypothetical sector growth over 30 years, assuming constant demand for each sector.
How is care managed?

- **Active case management:**
  - Preadmission review
  - Continued-stay review
  - Second surgical opinion
- **Selective case management**—high-cost cohorts
- **Post-care management**
- **Institutional**
  - Capitation
  - Institutional arrangements (referrals, hospitals, pharmacies, …)
  - Control “leakage”
Managed Care Scorecard

• “U.M. has helped to reduce inpatient hospital use and to limit inpatient costs…”
• “The impact of U.M. on net benefit costs is less clear. Savings on inpatient care have been partially offset by increased spending for outpatient care and program administration.”
• “U.M. … does not appear to have altered the long-term rate of increase in health care costs.”
• “Decisions that were once the exclusive province of the doctor and patient now may be examined in advance by an external reviewer—someone accountable to an employer, insurer, health maintenance organization (HMO), or other entity responsible for all or most of the cost of care. Depending upon the circumstances, this outside party may be involved in discussions about where care will occur, how treatment will be provided, and even whether some treatments are appropriate at all.”

—IOM, 1989
Managed Care Opposition

“In those days there was no bureaucratic regimentation, there were few forms to fill out, malpractice premiums were affordable, and the overhead costs of running a practice were reasonable. Our bills were simple, spelled out so anybody could understand them without the use of codes. Patients usually paid their own bills, promptly too, for which an ordinary receipt was given. Hospital charges were set by the day, not by the aspirin. Medical care was affordable to the average person with rates set by the laws of the marketplace, and care was made available to all who requested it regardless of ability to pay. Doctors were well respected; rarely were we denigrated by a hostile press for political reasons. Yes, in the days before government intervention into the practice of medicine, doctor’s fees were low, but the rewards were rich; those were truly the ‘golden years’ for medicine.”

Edward Annis, past President of AMA

*Code Blue*, 1993
ObamaCare

• Universal coverage: everyone must get insurance
  – Employer
  – Insurance collaborative
  – Government (?) — rejected
• Insurance companies cannot deny insurance, cancel coverage, impose reimbursement limits based on illness, past or present
• Government assistance to poor people, small companies
• Health Information Technology (HIT) to smooth info flow
• Cost savings from avoiding billing disputes, ceasing to reimburse only procedures, evidence-based medicine
• Accountable Care Organizations
Hospital Readmissions Reduction Program

Excess readmission: within 30 days of discharge

- CMS uses excess readmission ratios (ERR) for:
  - Acute Myocardial Infarction (AMI)
  - Chronic Obstructive Pulmonary Disease (COPD)
  - Heart Failure (HF)
  - Pneumonia
  - Coronary Artery Bypass Graft (CABG) Surgery
  - Elective Primary Total Hip Arthroplasty and/or Total Knee Arthroplasty (THA/TKA)
Quality Improvement

• IOM Study: 96,000 US deaths/year from medical error (perhaps half preventable?)
• Information intervention *at the point of decision making* can improve decisions
• DPOE: Direct Physician Order Entry allows such intervention
• Leapfrog Group: Large employers ($$$) require DPOE from providers
• Patient Involvement: Indivo Health, Google Health, Microsoft Healthvault
  • *So far, all commercial failures*
Implications of Health Care Organization for Informatics

- Money determines much
  - Historically, medicine spends 1-2% on IT, vs. 6-7% for business overall, vs. 10-12% for banking
  - "Bottom line" rules, therefore emphasis on
    - Billing
    - Cost control
    - Quality control, especially if demonstrable cost savings
    - Retention and satisfaction (maybe)
  - Management by accountants
    - Slowly changing
Quo Vadis?

• Anticipated improvements in health care should give us better information
  • Genomic medicine
    • Genome, transcriptome, proteome, epigenome, metabolome, meta genome, …
  • Improved instrumentation, e.g.,
    • non-invasive examination of the body: ultrasound, MRI, CT, swallowable capsules, …
    • continuous recording: MEMS implantable devices, …
• Improved methods of data analysis, causal discovery, biology research, … should give us better understanding
• New interventions can improve therapy
  • Gene editing: CRISPR-CAS9, …
  • Targeted delivery of drugs to specific tissues
“Oh, the future’s so bright, we’ll have to wear sunglasses!”
-- Barbara Kooymen, Timbuk 3
-- with thanks to Phil Greenspun

https://hst.mit.edu/admissions/gems-faq