

Making Sense of Data: Digital Revolution in the Management of Complex Systems – and the dairy industry

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D4Dairy KickOff Meeting, Nov 5 2018



managing a system

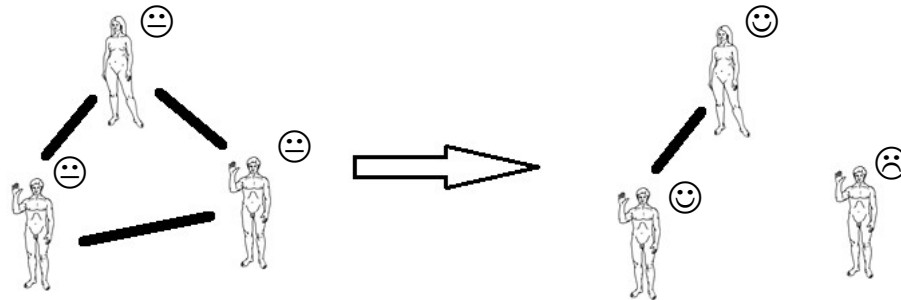
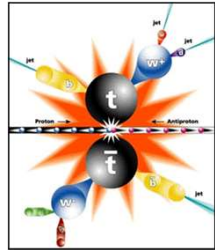
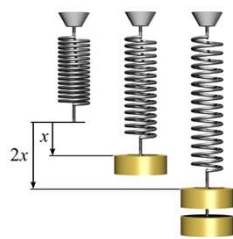
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ability ***to predict*** the results of possible actions and
interventions

Without this ability we do not manage—we play roulette.

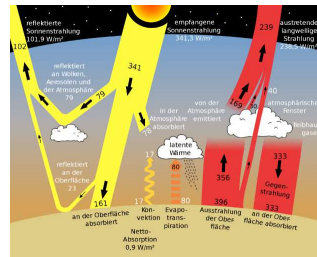
Which systems *can* we predict?

- Very, very small ones ($\sim 1-10$ components)



Have a chance to get the laws right (physics, sociology, ...)!

- Very, very large ones ($\sim 10^{28}$ components)



Statistics works!

Complex Systems

- Too large and heterogeneous to get all the laws right.
- Too small, dynamic, and interdependent to use standard statistics.
- Consequence: „Everything is so complicated ...“

- Status quo 2018?



"Ich weiß schon, meine Damen und Herren, das alles ist sehr kompliziert so wie diese Welt, in der wir leben und handeln, und die Gesellschaft, in der wir uns entfalten wollen. Haben wir daher den Mut, mehr als bisher auf diese Kompliziertheit hinzuweisen; zuzugeben, daß es perfekte Lösungen für alles und für jeden in einer pluralistischen Demokratie gar nicht geben kann."

Fred Sinowatz Regierungserklärung 31. Mai 1983,

What are Complex Systems?

- Complex Systems consist of many components.
- These components have specific properties and interact with each other.
- Details matter! Who interacts with whom under which circumstances?
- Interactions change the properties of the system.
- Changing properties alter the interactions of the components.

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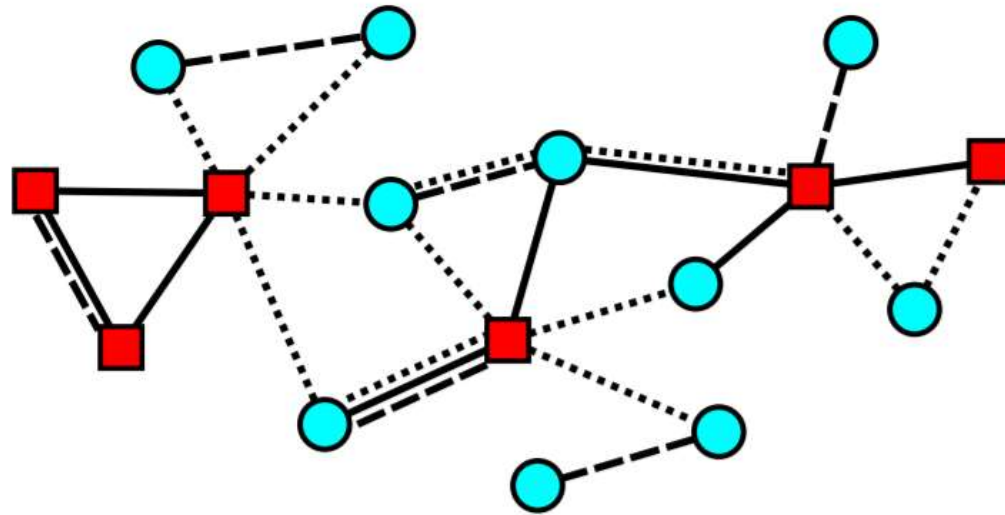
- Interactions change the properties of the system.
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These feedbacks are what makes Complex Systems complex!

What are Complex Systems?

- Complex Systems are co-evolving multiplex networks.



- States of individuals/firms/... change as a function of the networks.
- Networks change the states of the individuals.



$n = \text{all}$

(„big data“)

Managing Complex Systems

- Gamechanger 1: **New data.**
 - Digital fingerprints form all areas of life.
 - Storage and computing power extremely cheap.
- Gamechanger 2: **New methods.**
 - New maths: network theory (each dataset is a network!), dynamical stochastic processes, ...
 - New statistics: inference, data mining, machine learning, full scale simulation
- New data → All properties & their changes can be seen in vivo in the data.
- New methods → Interaction networks can be learned from the data.
- → **Complex Systems can be managed!**
(a first in the history of mankind)

Managing Complex Systems

Gamechanger 1: New data.

Big data comes from all areas of life.

- Storage power extremely cheap.

Gamechanger 2: New

- New maths: network theory (e.g. dynamical stochastic processes, ...)
- New statistics: inference, data mining, machine learning, large scale simulation

• New data → All properties & their changes can be seen in the data

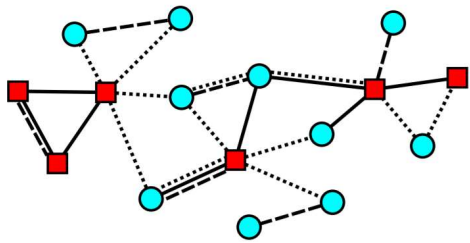
• New methods → Interaction networks can be learned from the data

• → **Complex Systems can be managed!**

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Big data without big theory is BS!

Example: Health & Medicine



Disentangling myriads
of risk factors and their
impact on health

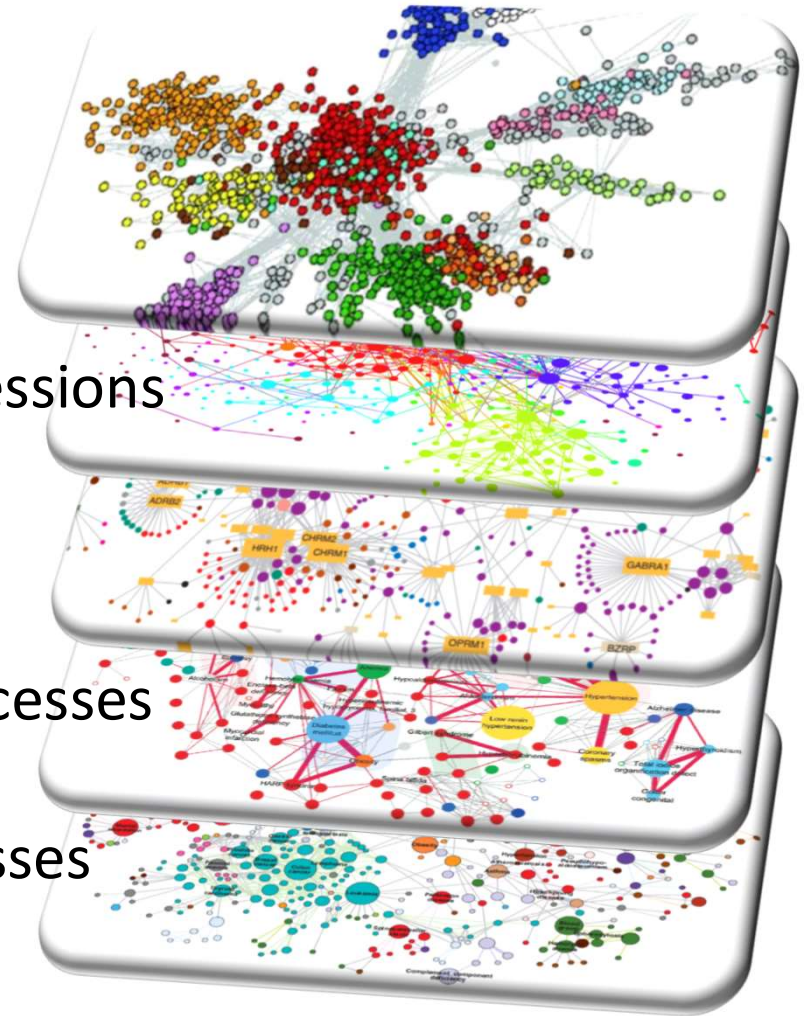
Patient flows

Disease progressions

Therapies

Metabolic processes

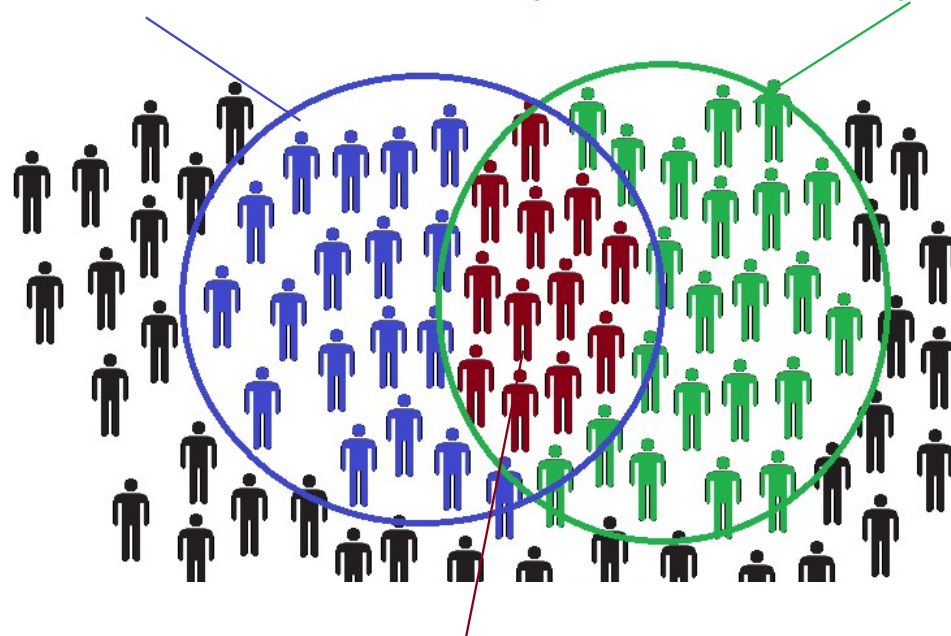
Genetic processes



How healthy is Austria?

patients with diabetes

patients with pancreatic cancer



patients with diabetes *and* pancreatic cancer

diabetes

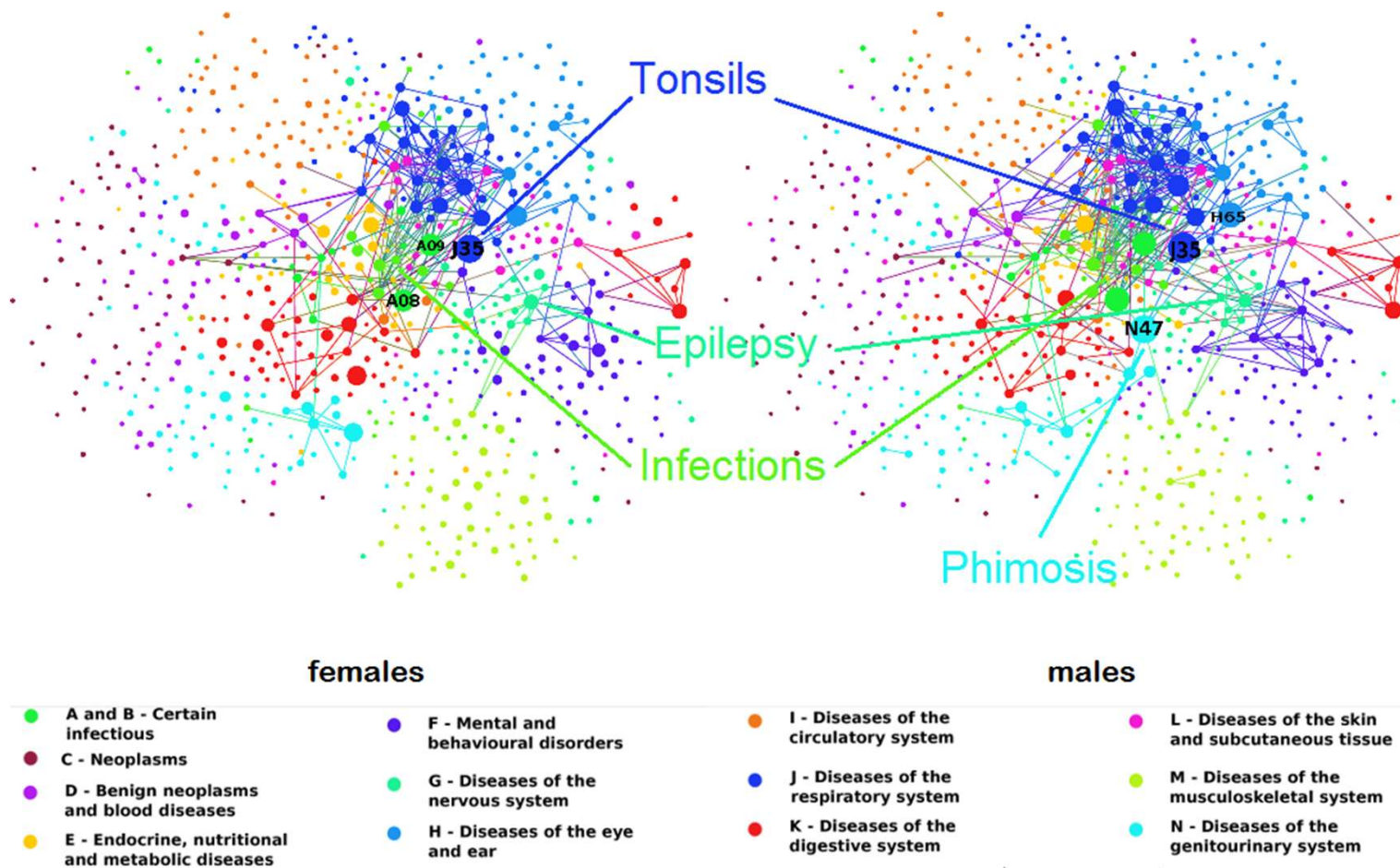


pancreatic cancer

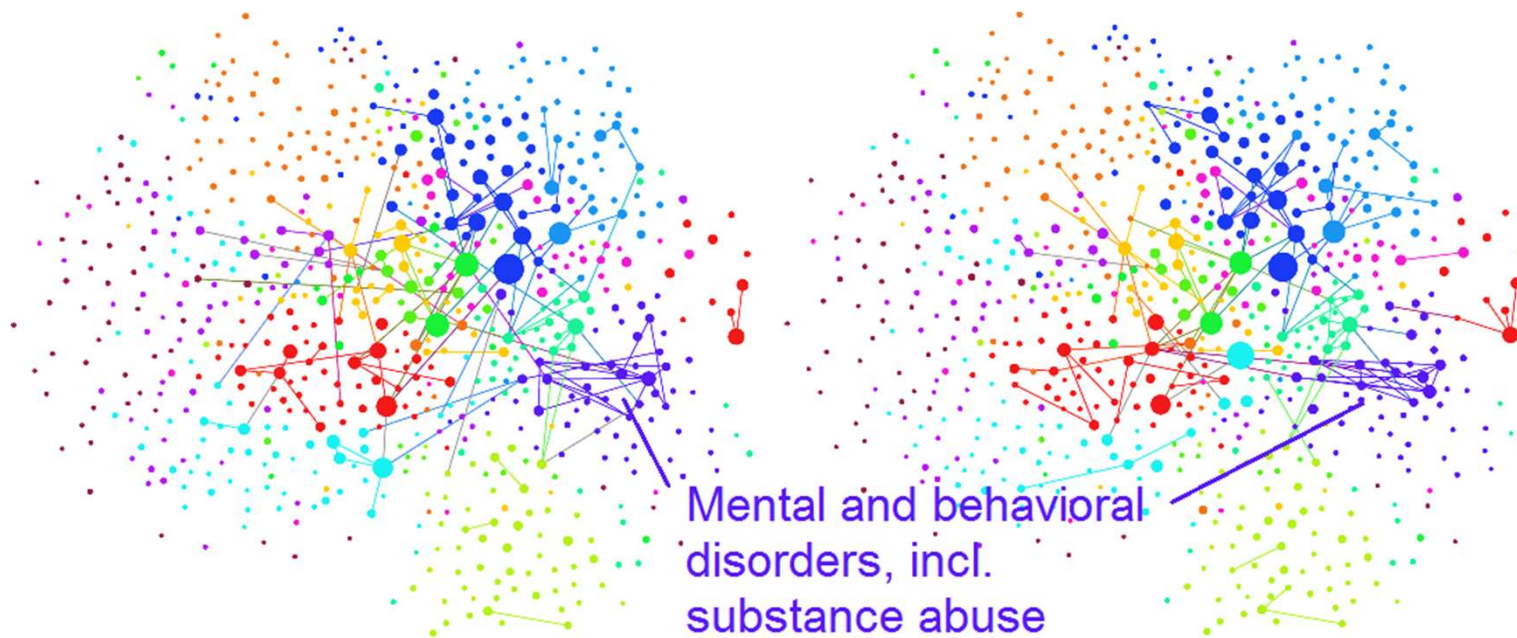
- nodes = diseases
- links = diseases are often co-occurring
- size of nodes = disease prevalence

Source: medical claims data for Austria (inpatient & outpatient sector)
8M patients, 2y, 2M hospitalizations, 100M encounters

Comorbidity networks



Comorbidity networks



females

- A and B - Certain infectious
- C - Neoplasms
- D - Benign neoplasms and blood diseases
- E - Endocrine, nutritional and metabolic diseases

- F - Mental and behavioural disorders
- G - Diseases of the nervous system
- H - Diseases of the eye and ear

males

- I - Diseases of the circulatory system
- J - Diseases of the respiratory system
- K - Diseases of the digestive system

- L - Diseases of the skin and subcutaneous tissue
- M - Diseases of the musculoskeletal system
- N - Diseases of the genitourinary system

0-8 years



9-16 years



17-24 years



25-32 years



33-40 years



41-48 years



49-56 years

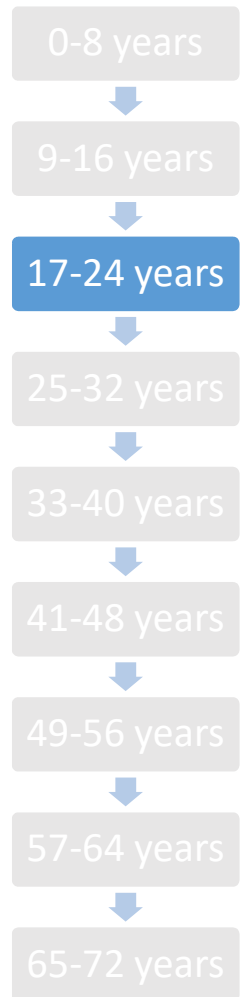
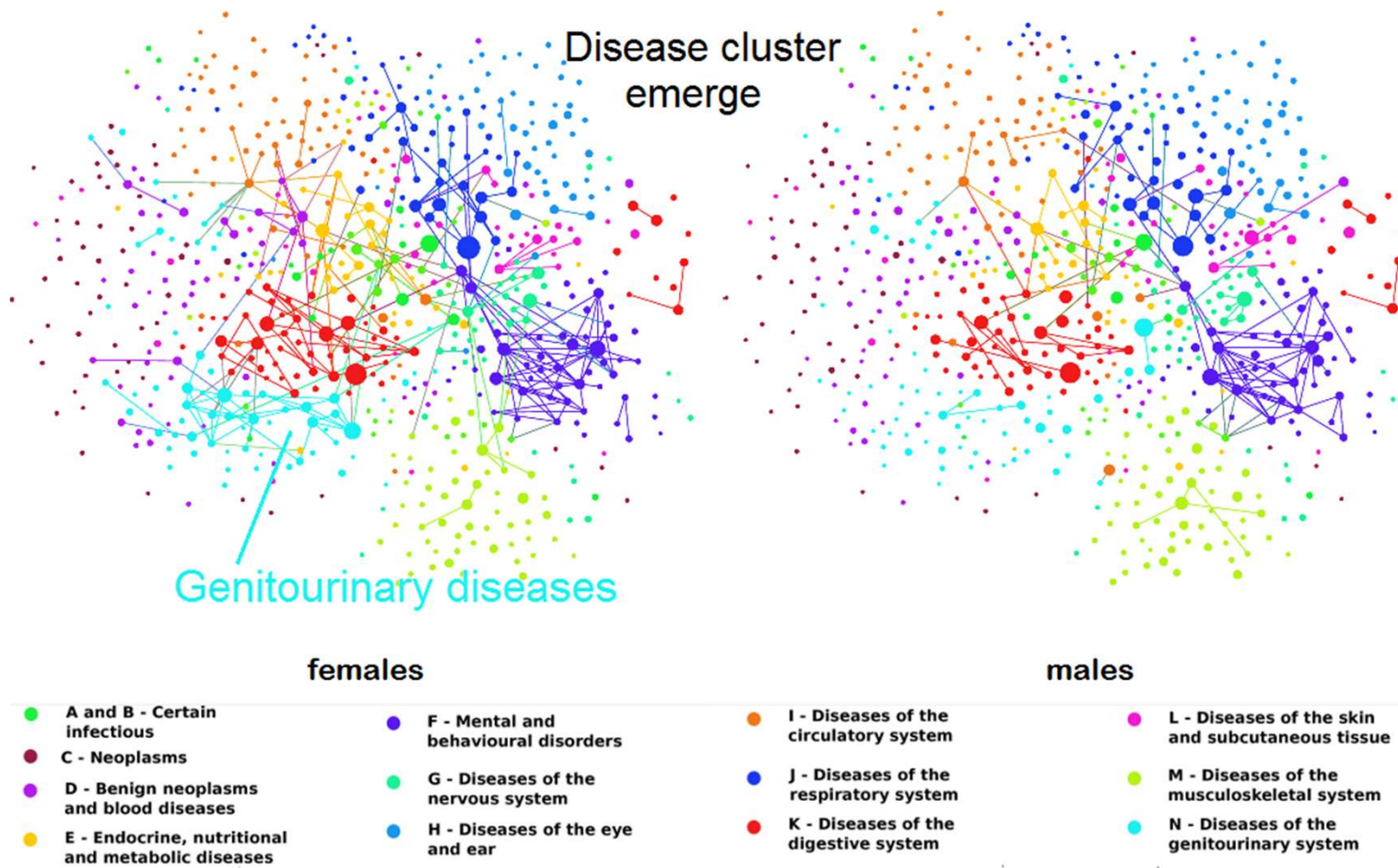


57-64 years

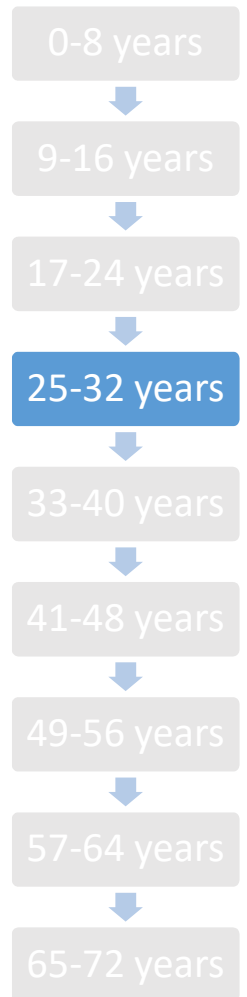
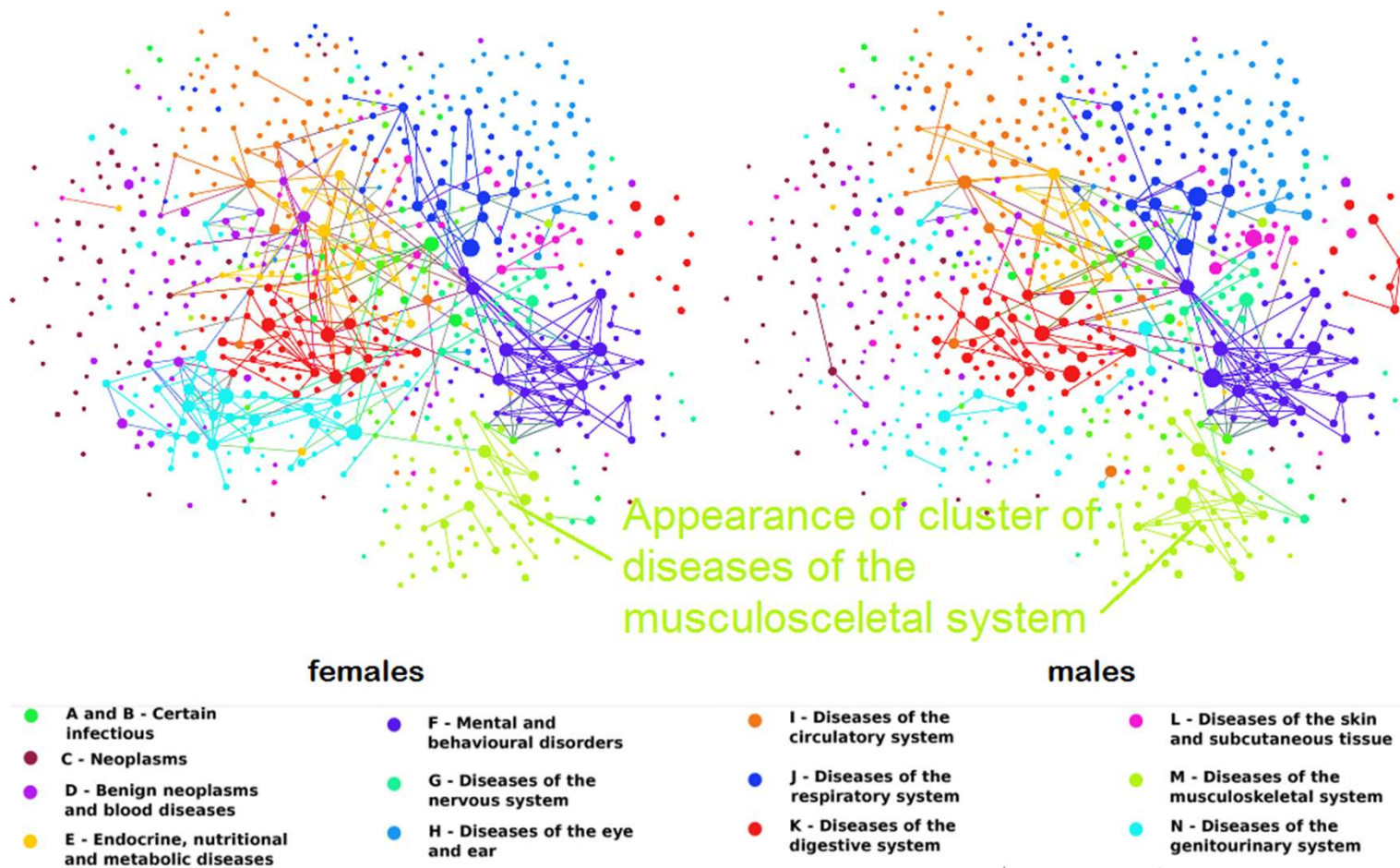


65-72 years

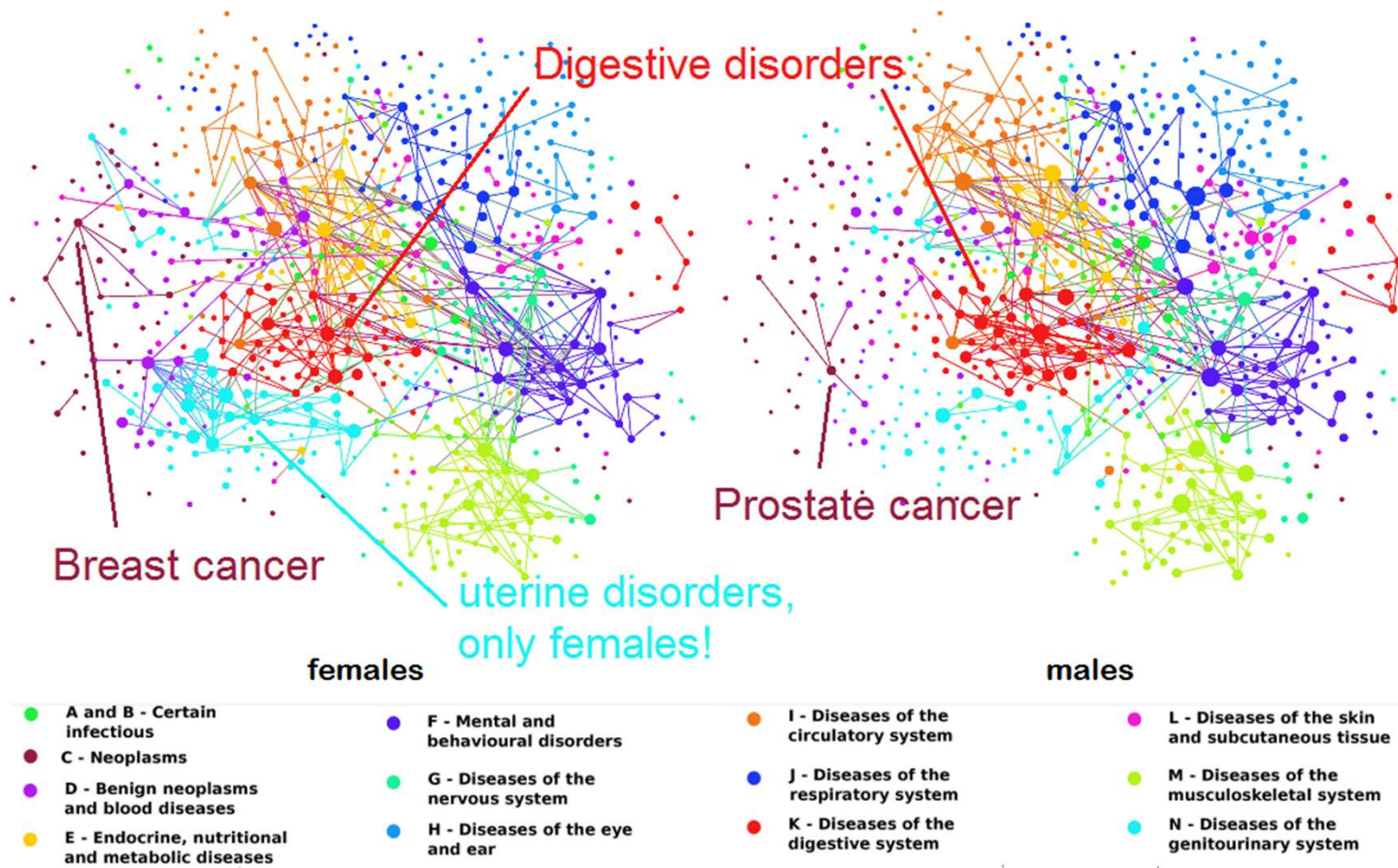
Comorbidity networks



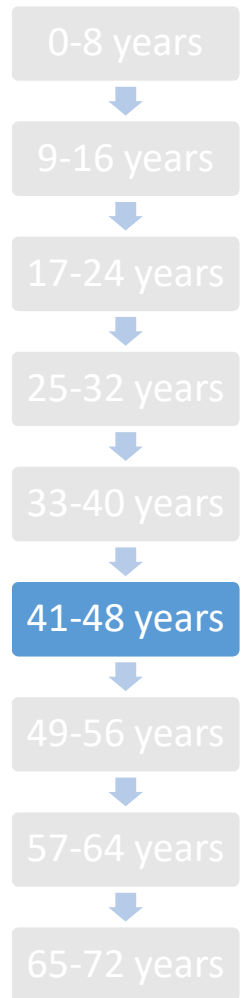
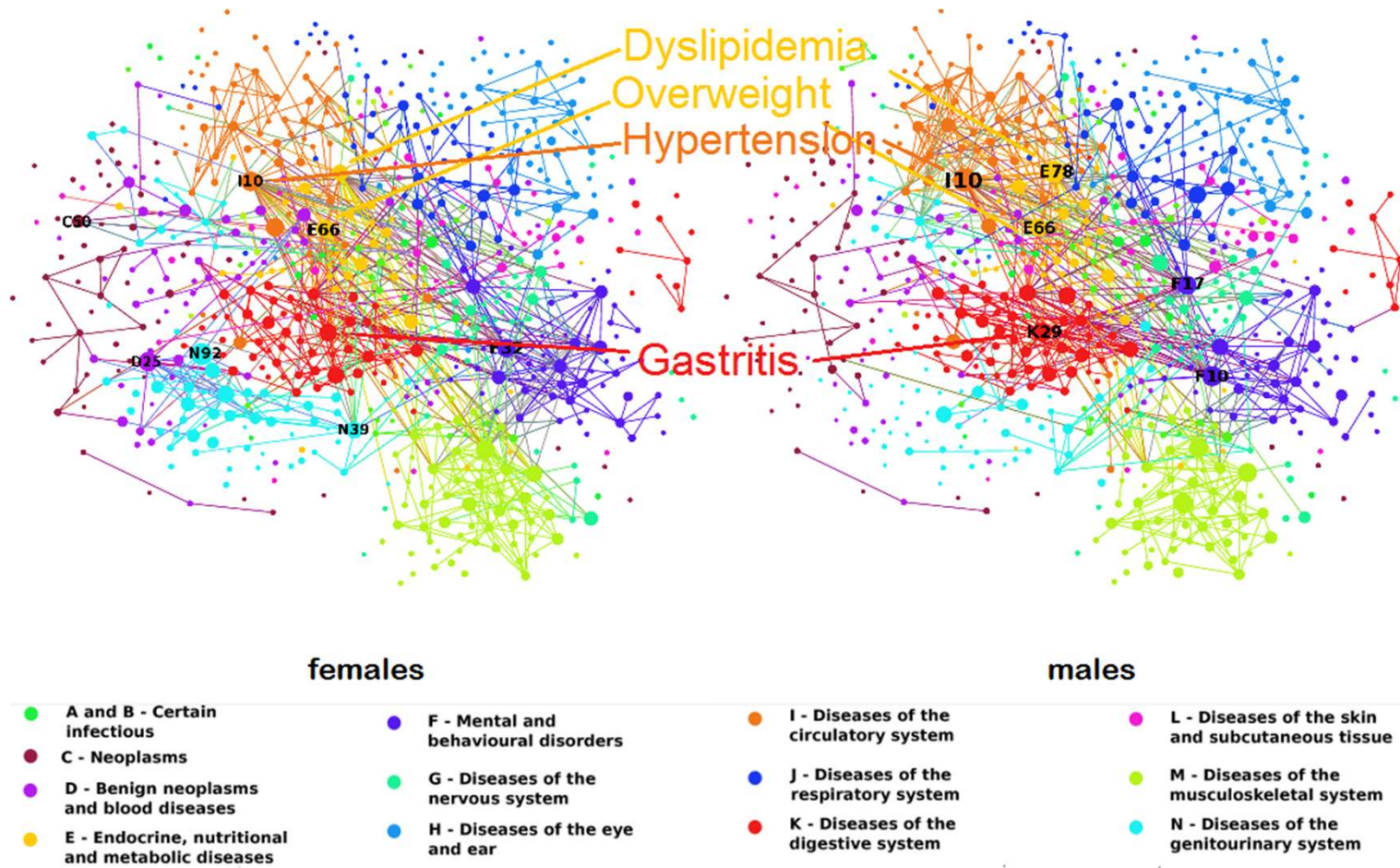
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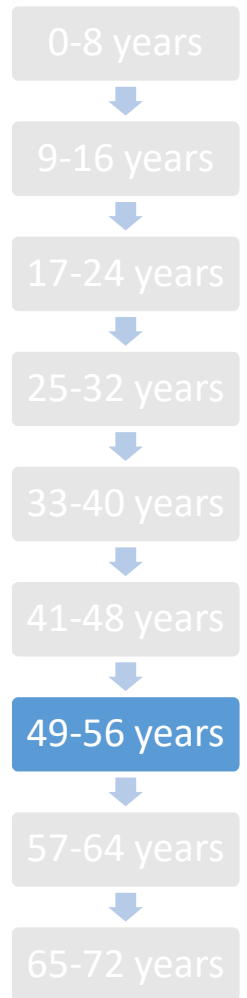
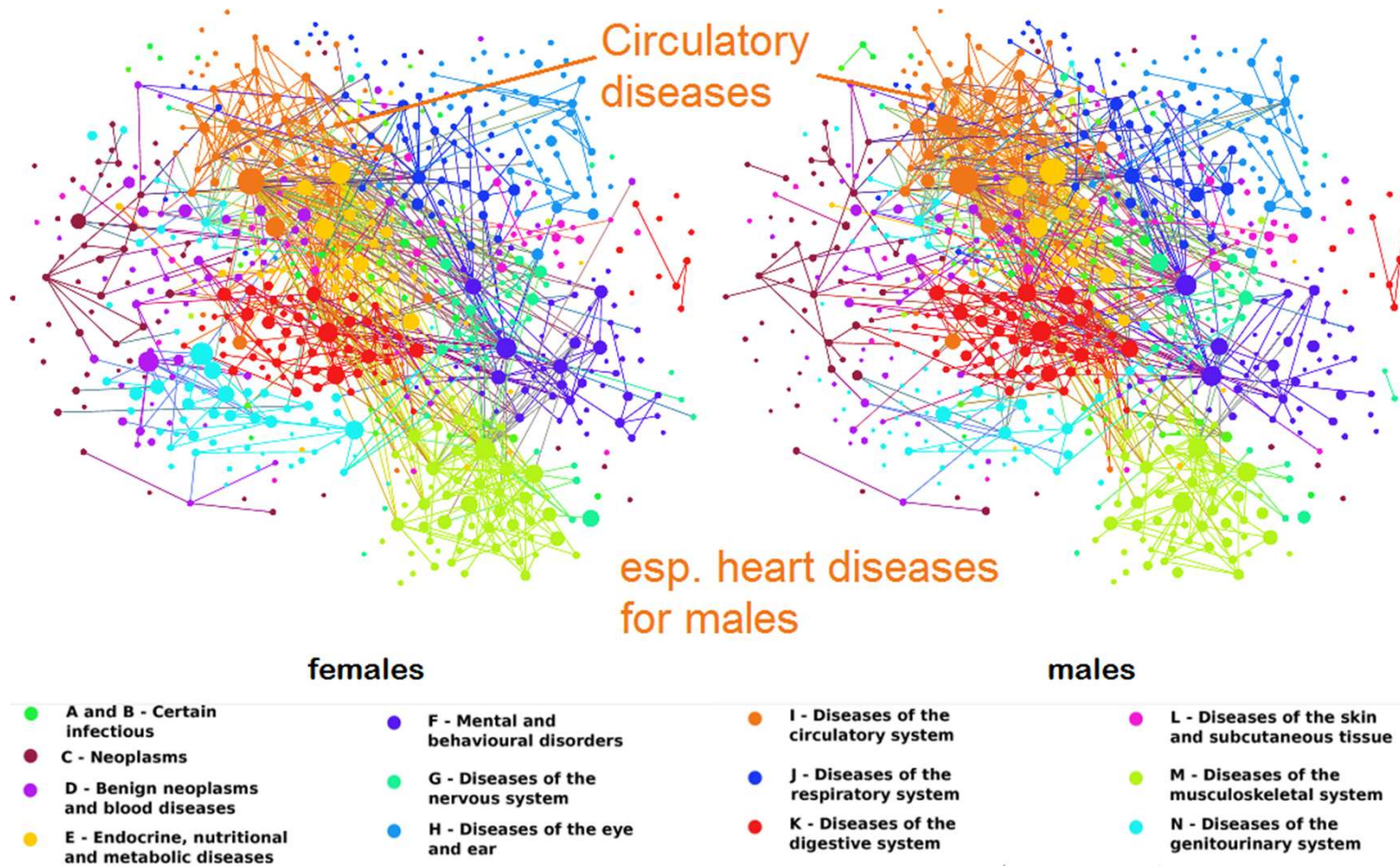
Comorbidity networks



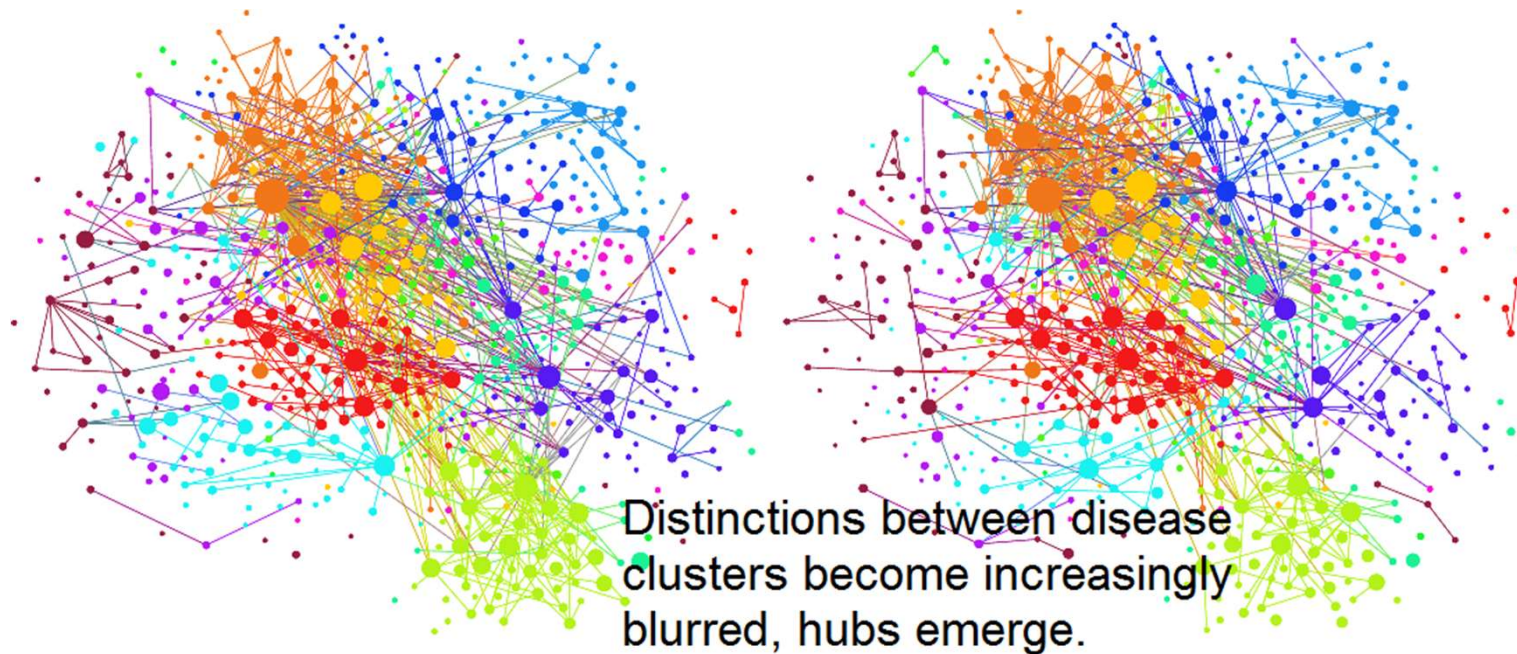
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Comorbidity networks



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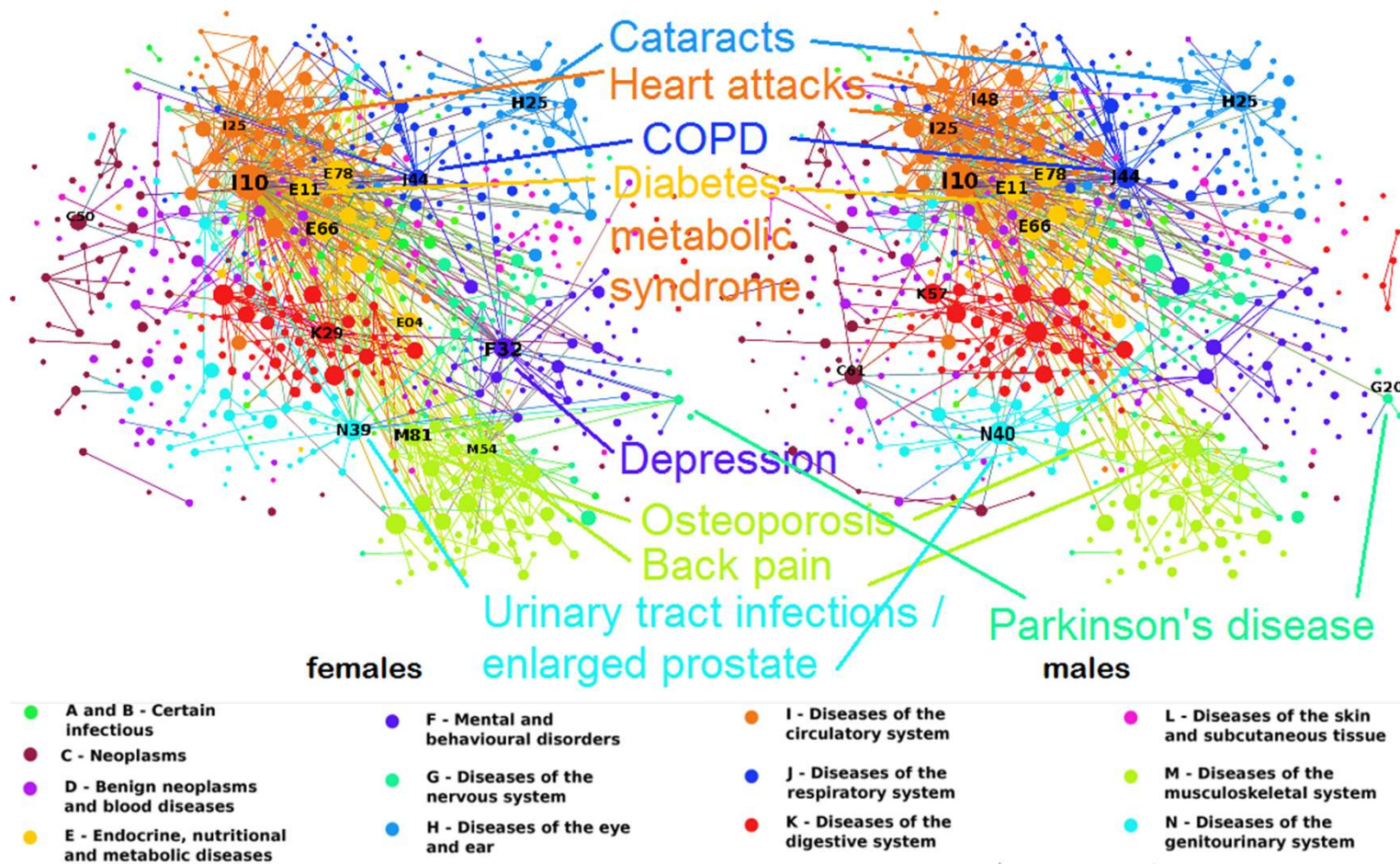


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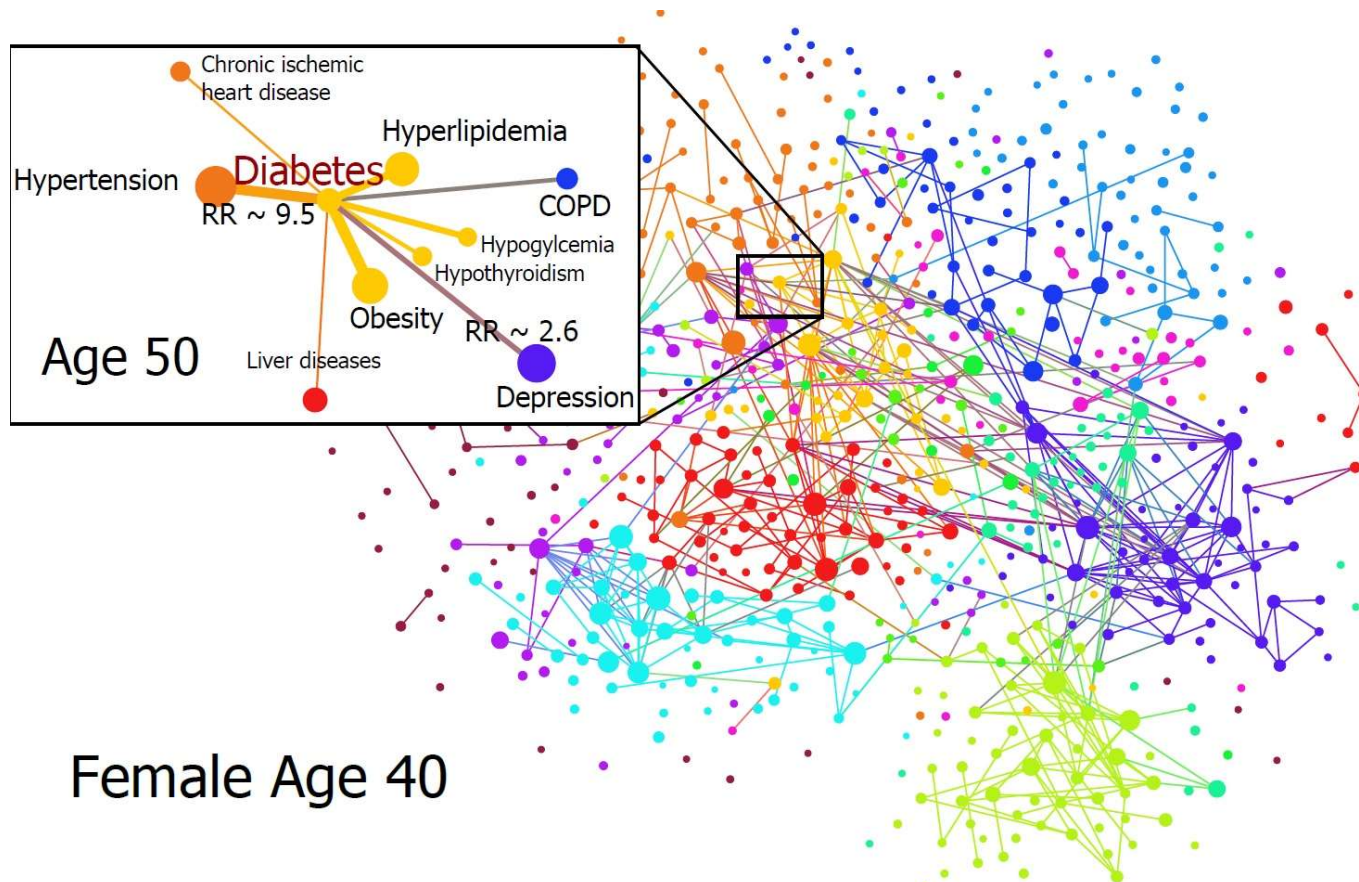
Comorbidity networks



Patients acquire diseases that are in close network-proximity to those that they already suffer.

Chmiel A, Klimek P, Thurner S, New J Phys 16, 115013 (2014)

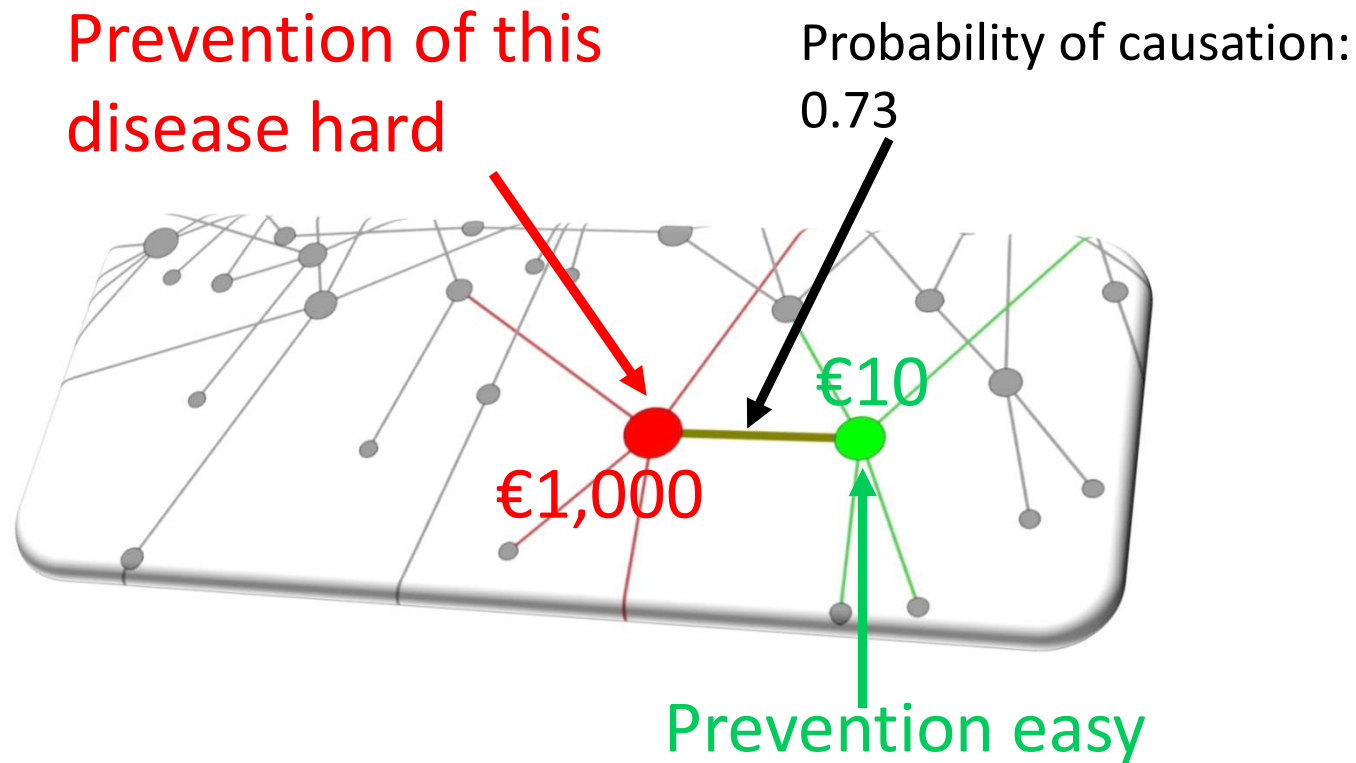
Predict incidences using comorbidity networks



population-wide
forecast of 85%-95%
of all disease
incidences within the
next ten life years

Chmiel A, Klimek P, Thurner S, New J Phys 16, 115013 (2014)

Comorbidity networks and prevention

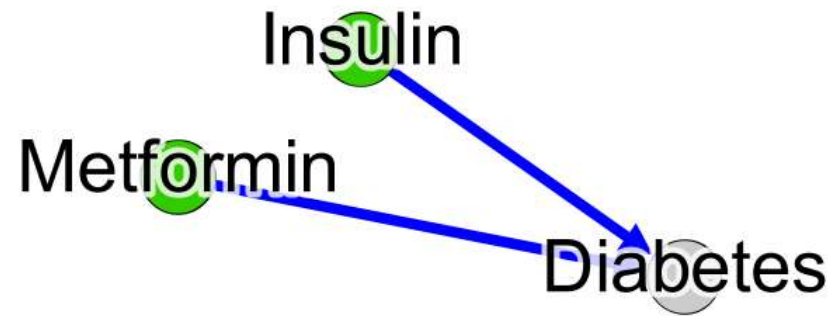


Identify comorbidities → Check causation → Treat causing diseases

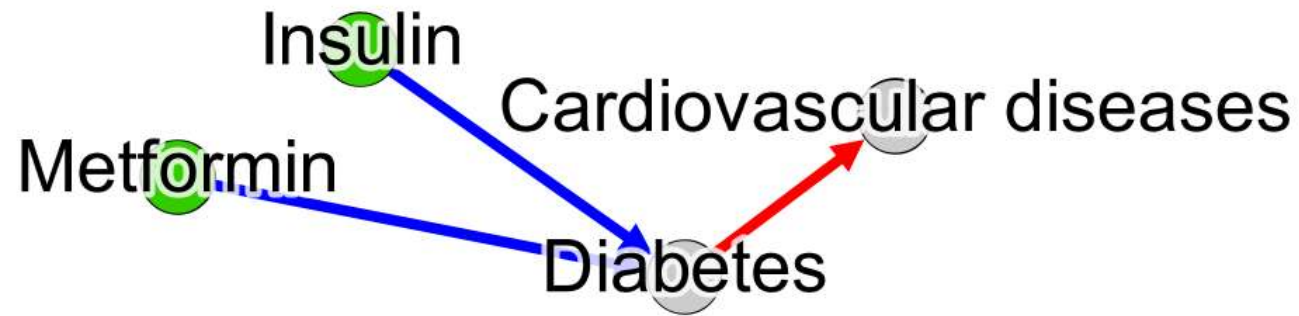
Comorbidity networks and polypharmacy

Diabetes

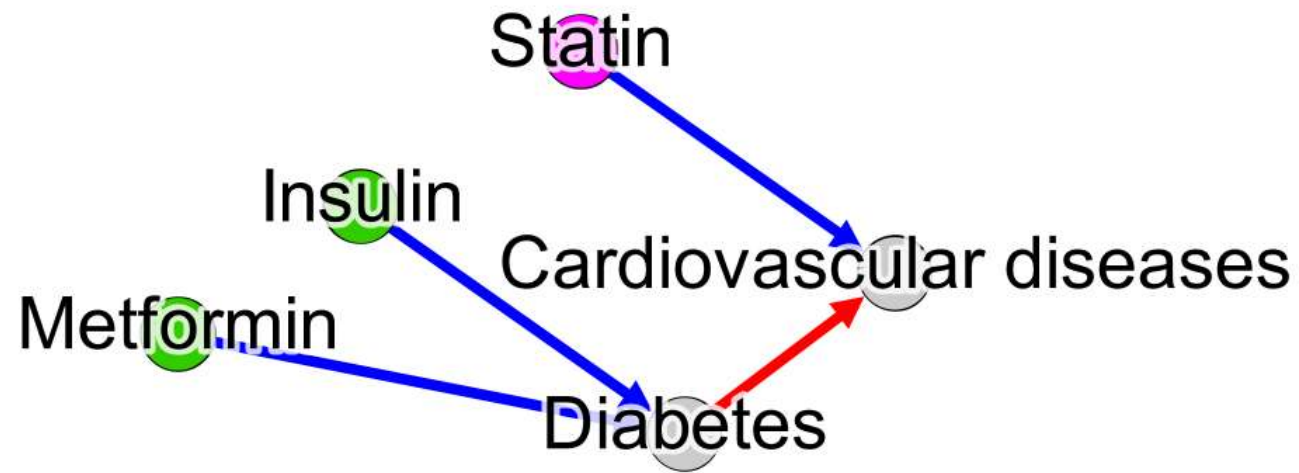
Comorbidity networks and polypharmacy



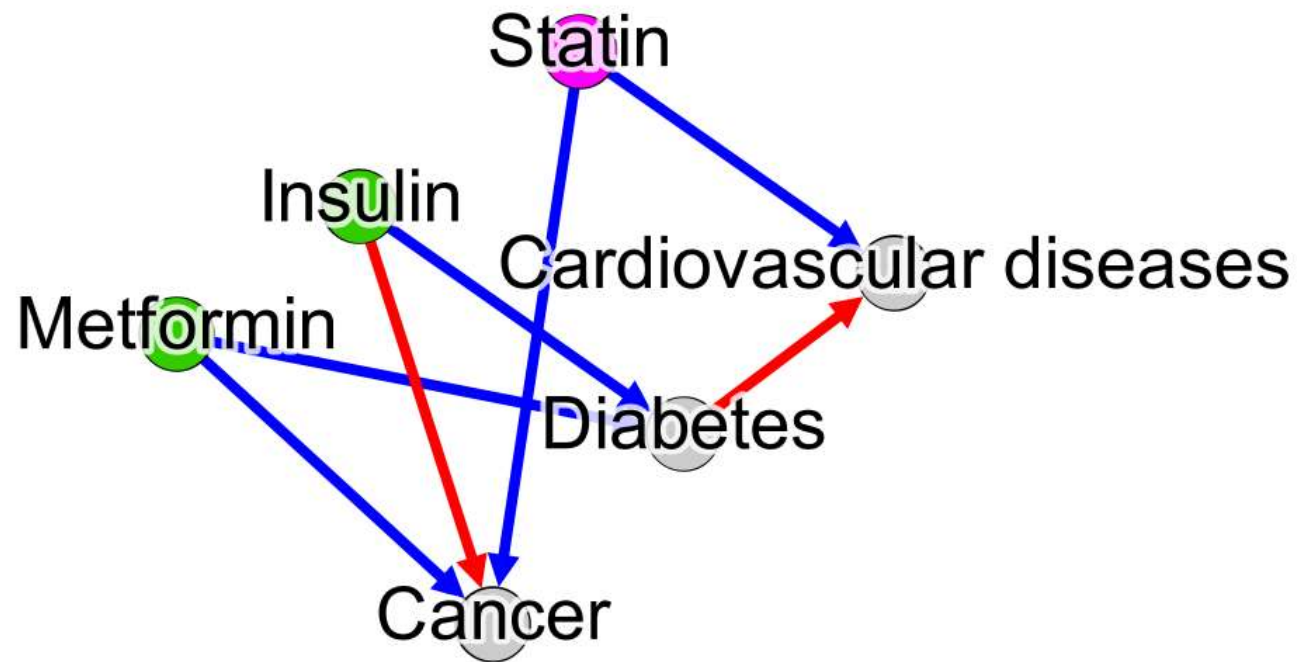
Comorbidity networks and polypharmacy



Comorbidity networks and polypharmacy

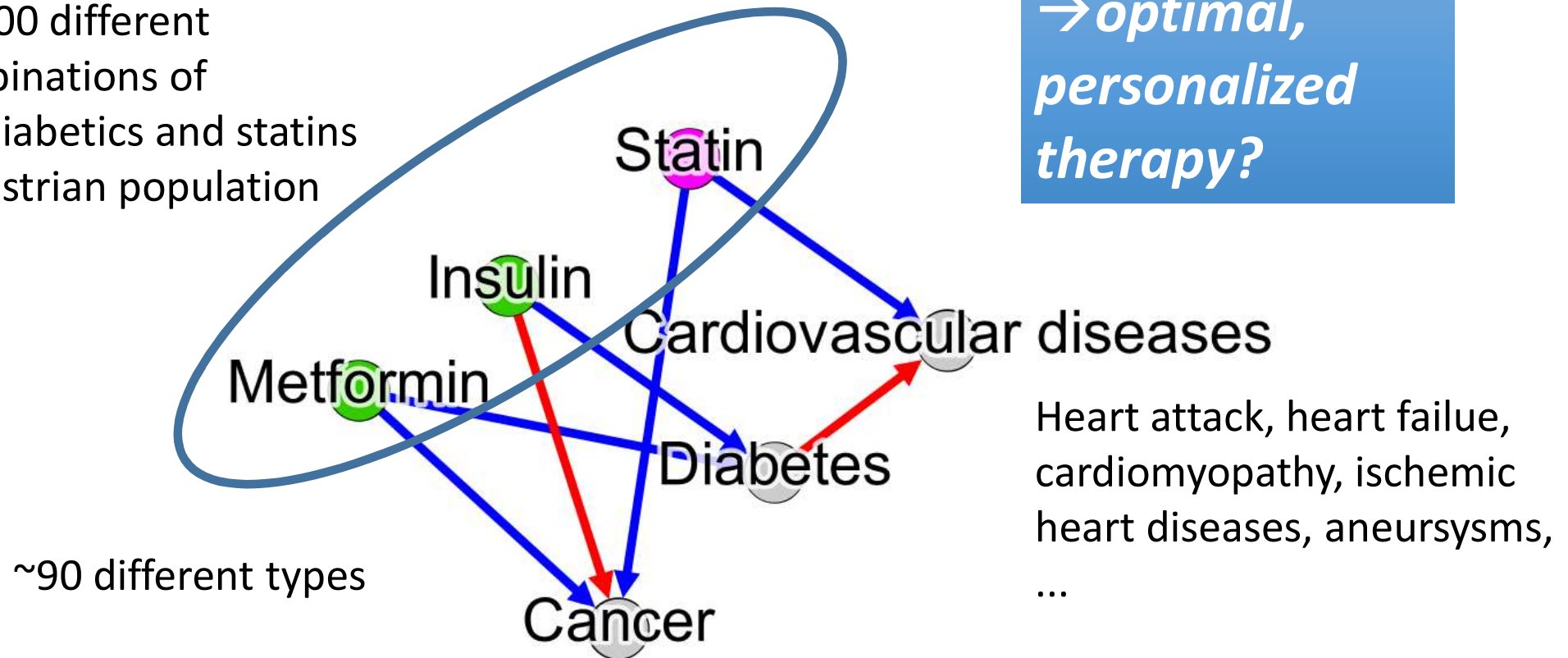


Comorbidity networks and polypharmacy

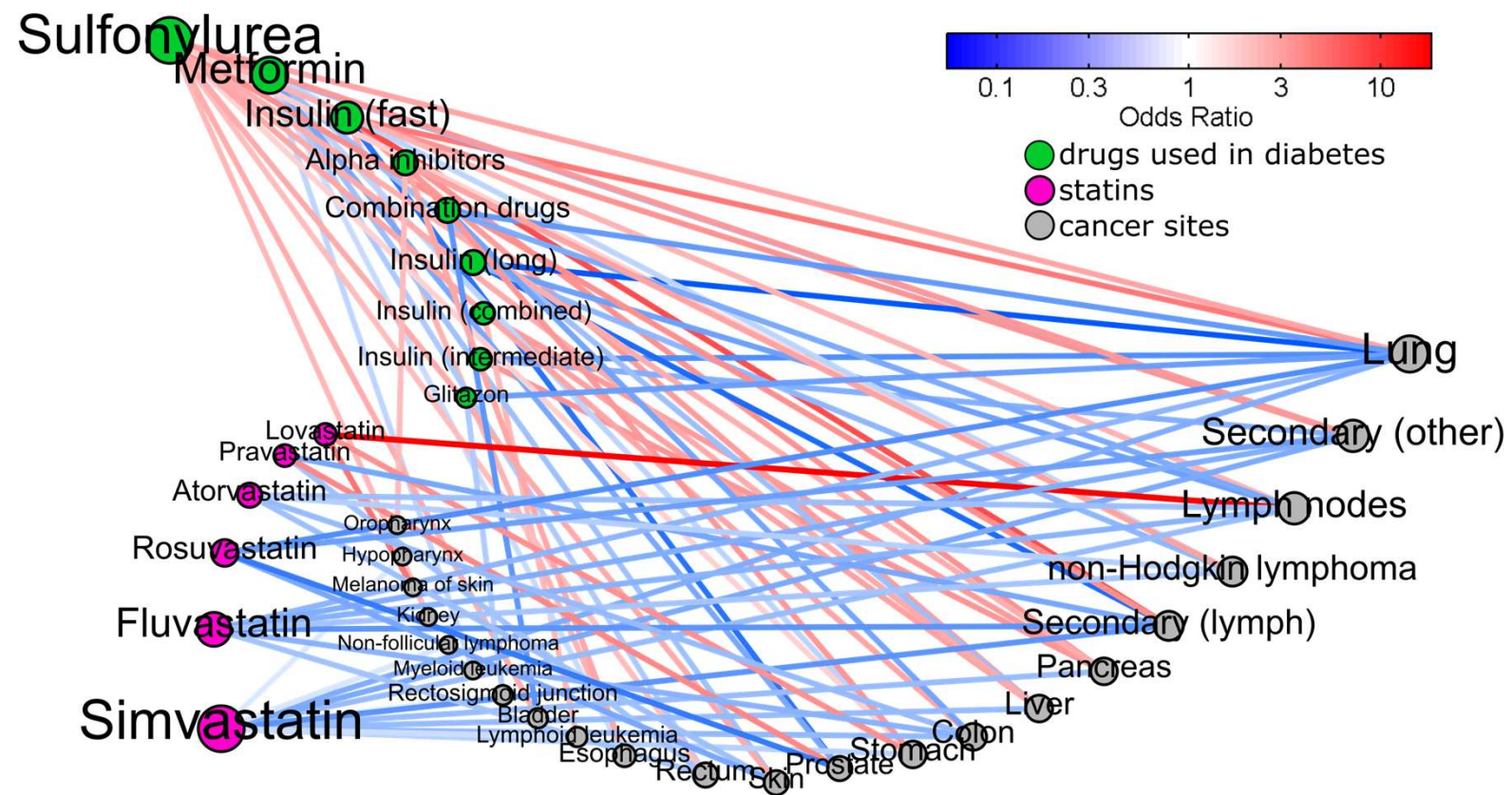


Comorbidity networks and polypharmacy

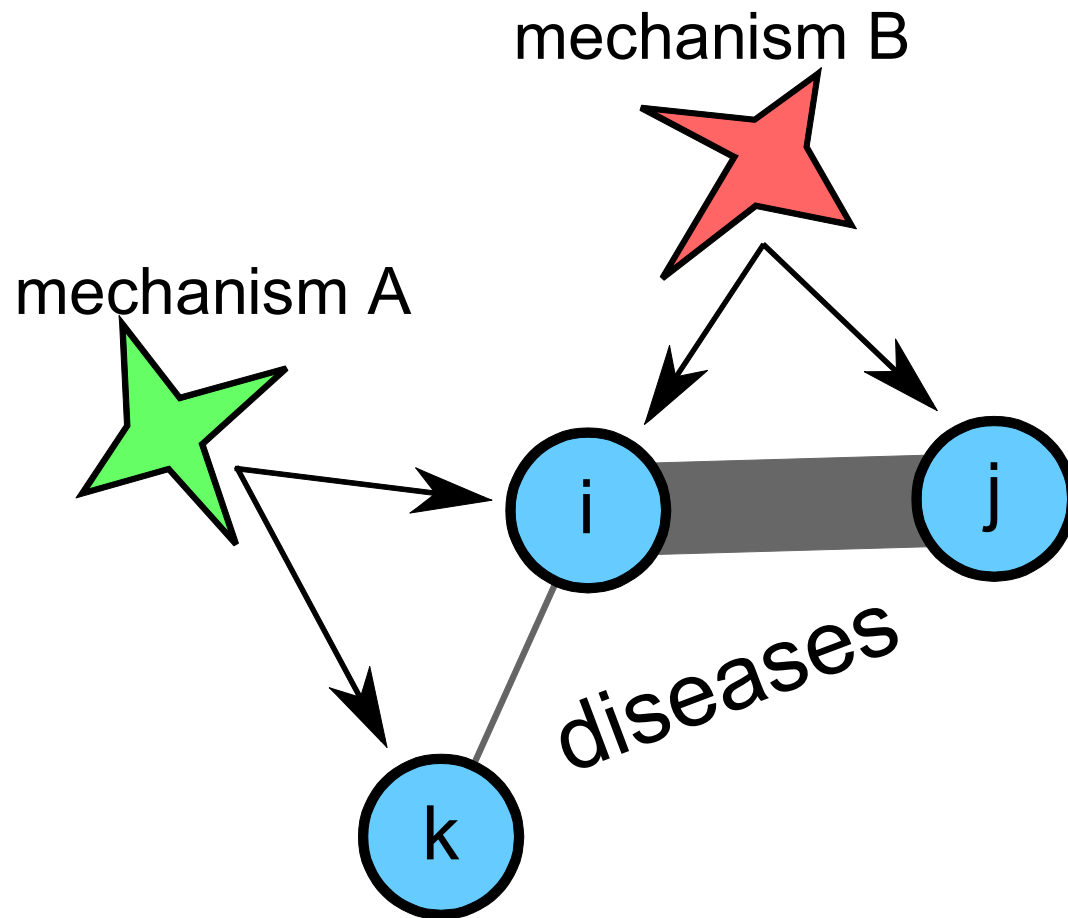
ca. 300 different combinations of antidiabetics and statins in Austrian population



Comorbidity networks and polypharmacy

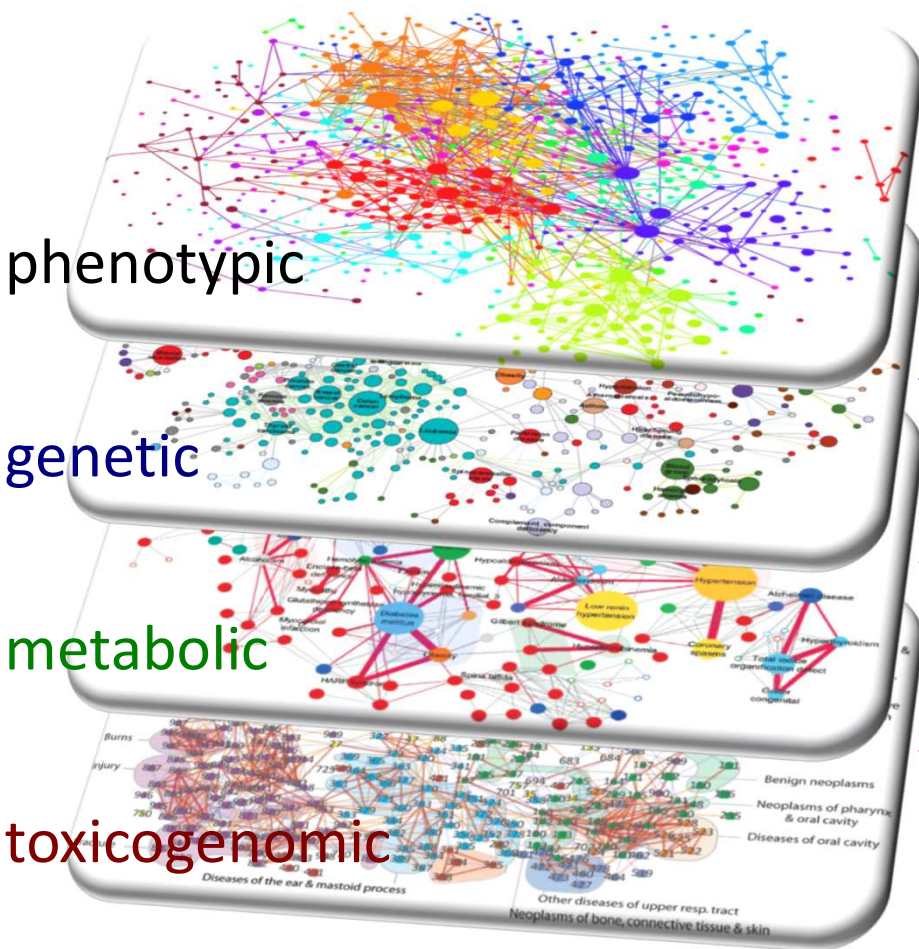


How (non)-genetic is a disease?



Disease mechanism B (e.g. genetic defect, exposure to environmental chemical, ...) explains disease phenotype j much better than mechanism A

How (non)-genetic is a disease?



molecular comorbidity networks:

Two diseases are comorbid if they relate to the same

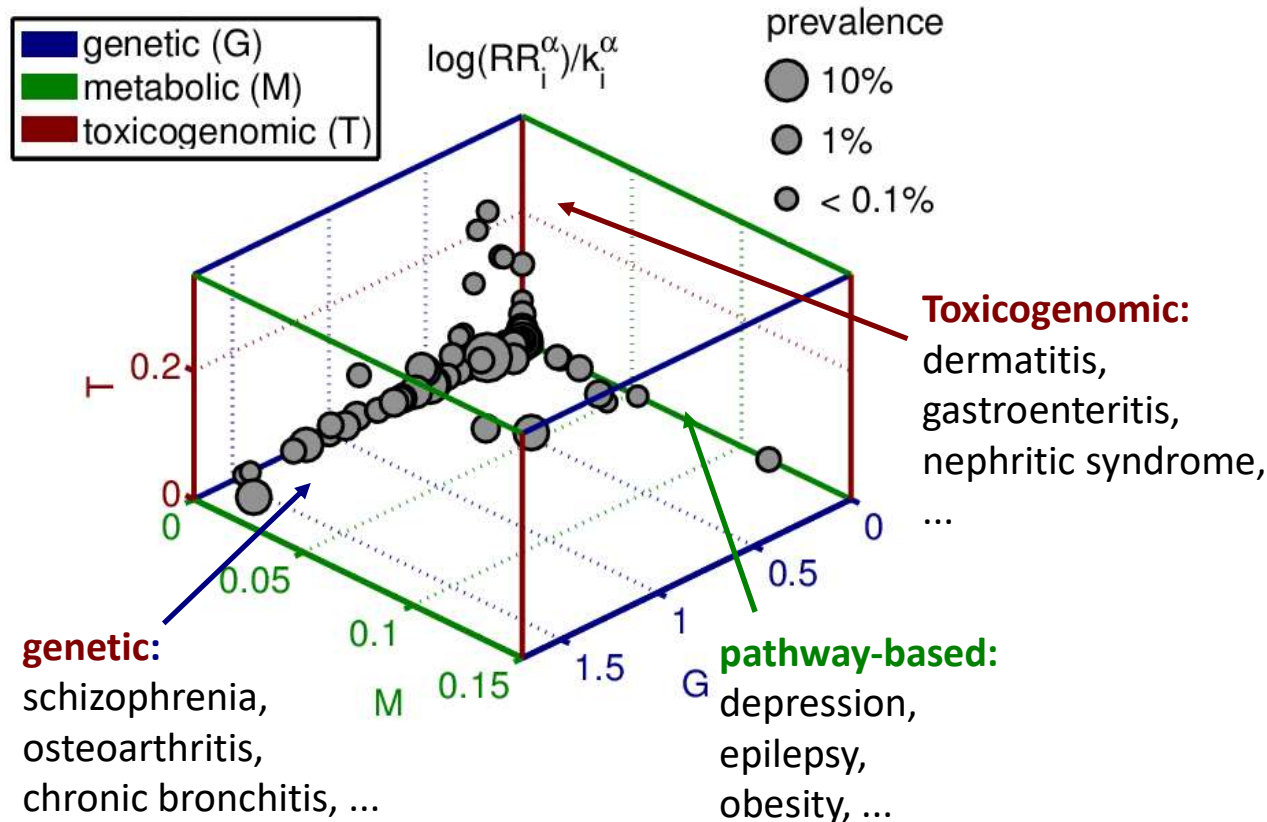
genetic,

metabolic, or

toxicogenomic

pathobiological mechanism.

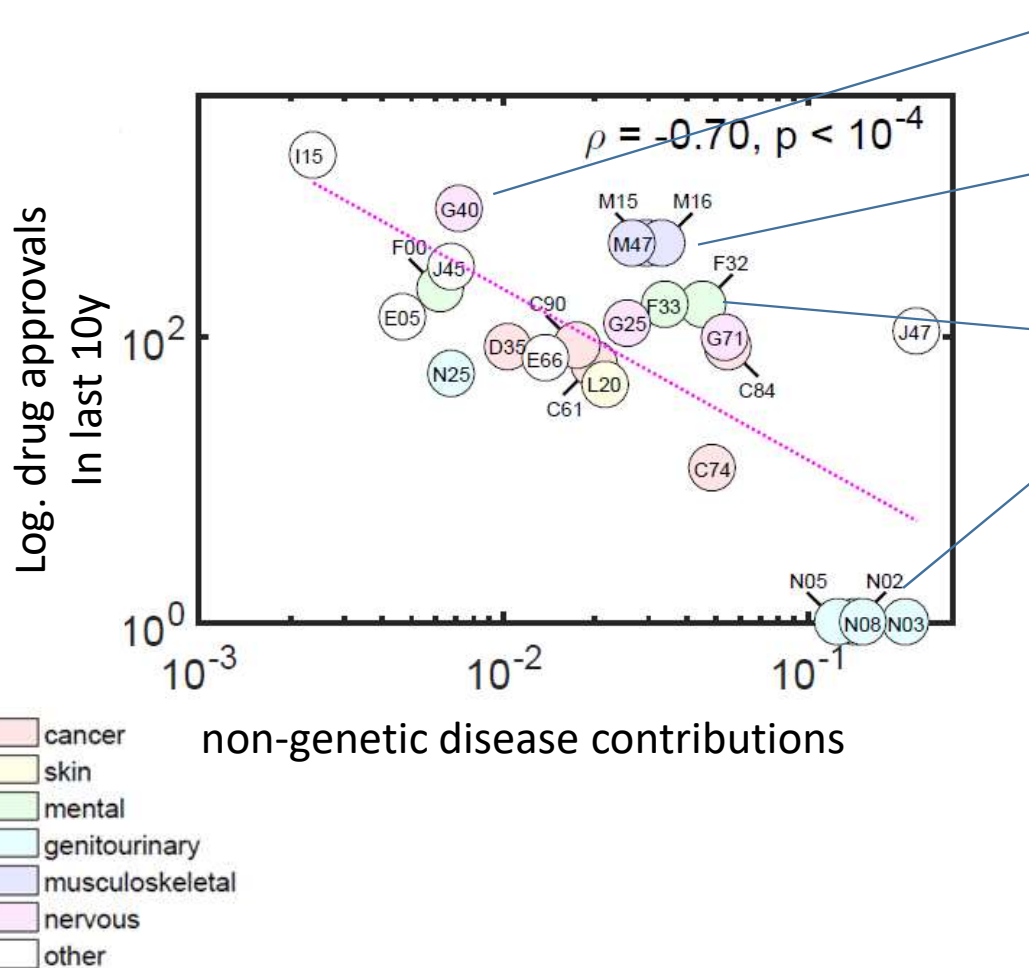
Individual disease risks



rank	genetic, $\alpha = G$	r_i^α	p_i^α
1	F25, Schizo-affective disorders	2.4	$< 10^{-4}$
2	F20, Schizophrenia	2.4	$< 10^{-4}$
3	M19, Osteoarthritis (unspecified)	2.9	$< 10^{-4}$
4	N04, Nephrotic syndrome	2.2	$< 10^{-4}$
5	J41, Simple, mucopurulent chronic bronchitis	2.1	$< 10^{-3}$
6	J42, Chronic bronchitis (unspecified)	2.0	$< 10^{-3}$
7	M15, Polyosteoarthritis	2.6	$< 10^{-3}$
8	N03, Chronic nephritic syndrome	2.3	$< 10^{-3}$
9	F22, Delusional disorders	2.6	$< 10^{-3}$
10	M18, Osteoarthritis (first carpometacarpal joint)	2.5	$< 10^{-3}$
pathway-based, $\alpha = P$			
1	F32, Major depressive disorder, single episode	1.1	$< 10^{-3}$
2	F33, Major depressive disorder, recurrent	0.81	0.002
3	M85, Disorders of bone density and structure	1.8	0.003
4	G40, Epilepsy and recurrent seizures	0.65	0.003
5	E66, Overweight and obesity	0.83	0.006
6	E85, Amyloidosis	0.58	0.009
7	G25, Other extrapyramidal and movement disorders	0.66	0.010
8	H90, Conductive and sensorineural hearing loss	0.56	0.010
9	M21, Other acquired deformities of limbs	1.3	0.010
10	C90, Multiple myeloma, plasma cell neoplasms	0.90	0.011
toxicogenomic, $\alpha = T$			
1	I71, Aortic aneurysm and dissection	0.75	0.002
2	L21, Seborrheic dermatitis	0.65	0.002
3	L24, Irritant contact dermatitis	0.99	0.002
4	K52, Gastroenteritis and colitis	0.64	0.002
5	N03, Chronic nephritic syndrome	1.7	0.004
6	L20, Atopic dermatitis	1.2	0.004
7	L28, Lichen simplex chronicus and prurigo	0.69	0.006
8	L30, Unspecified dermatitis	0.58	0.006
9	I89, Noninfective disorders of lymphatic vessels and nodes	0.84	0.008
10	G91, Hydrocephalus	0.96	0.009

Most diseases with high pathway or toxicogenomic contributions have low (but >0) genetic ones → diseases cluster on axes!

Consequences für Pharma R&D



epilepsy

arthropathy

depression

glomerular disorders

The more non-genetic contributions to disease risk, the lower the number of successes in developing new drugs

THANK YOU!

W|W|T|F

WIENER WISSENSCHAFTS-,
FORSCHUNGS- UND TECHNOLOGIEFONDS



European
Commission

Horizon 2020
European Union funding
for Research & Innovation



FFG



Hauptverband der
österreichischen
Sozialversicherungsträger