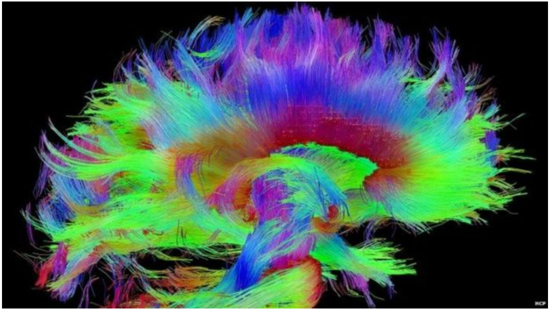
CS 4884: Brain Graphs

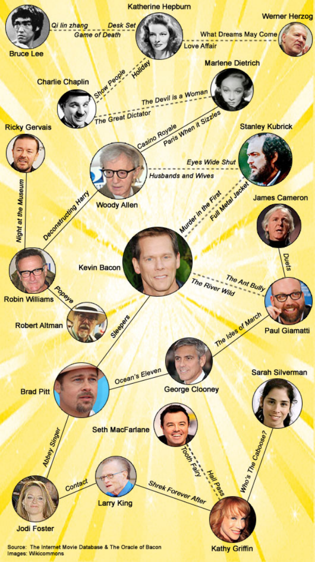
T. M. Murali

January 27, 2022



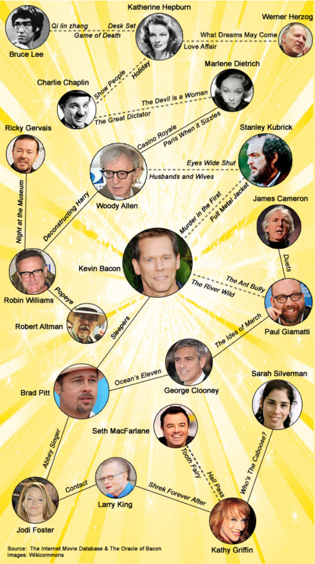
Creating Graphs

Node ≡ , Edge ≡



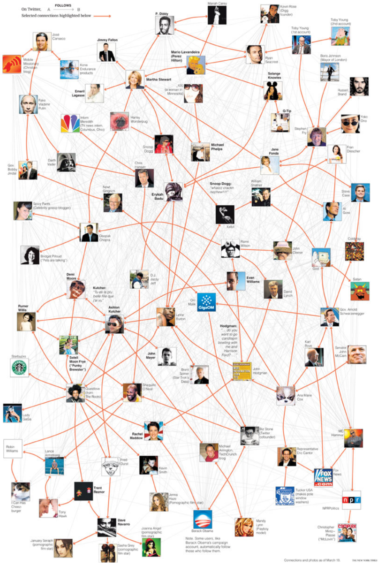
Creating Graphs

Node $\equiv$ Person, Edge $\equiv$ In same movie



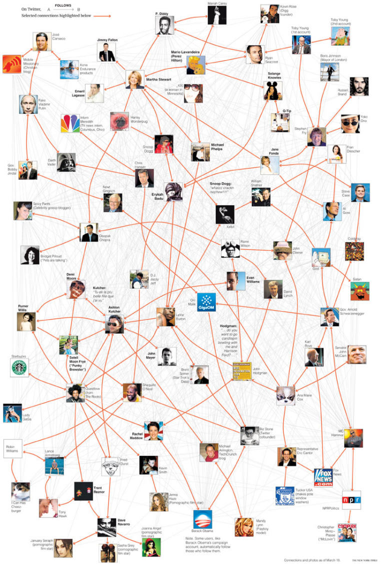
Creating Graphs

Node ≡ , Edge ≡



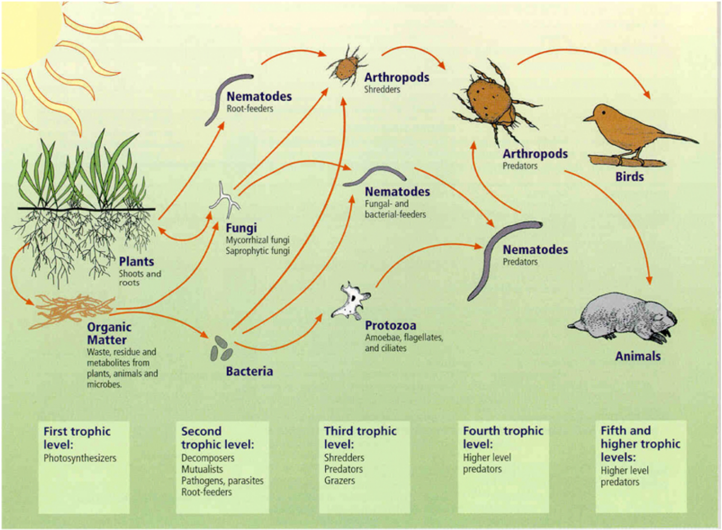
Creating Graphs

Node $\equiv$ Person, Edge $\equiv$ Follows on Twitter



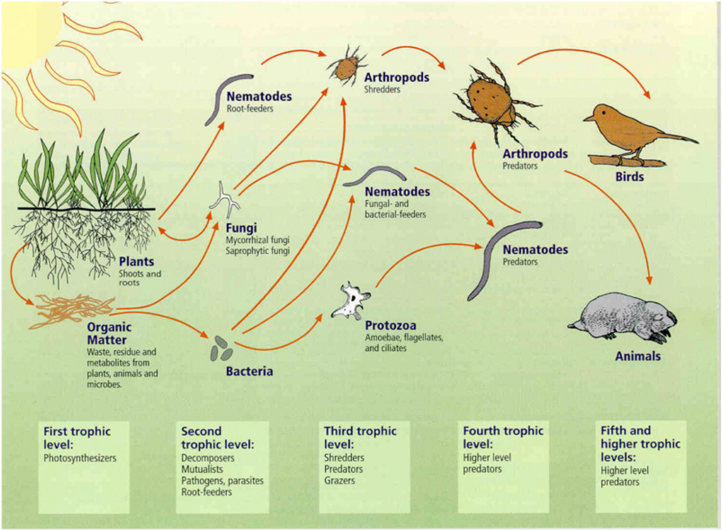
Creating Graphs

Node ≡ , Edge ≡



Creating Graphs

Node ≡ Organism, Edge ≡ Is eaten by

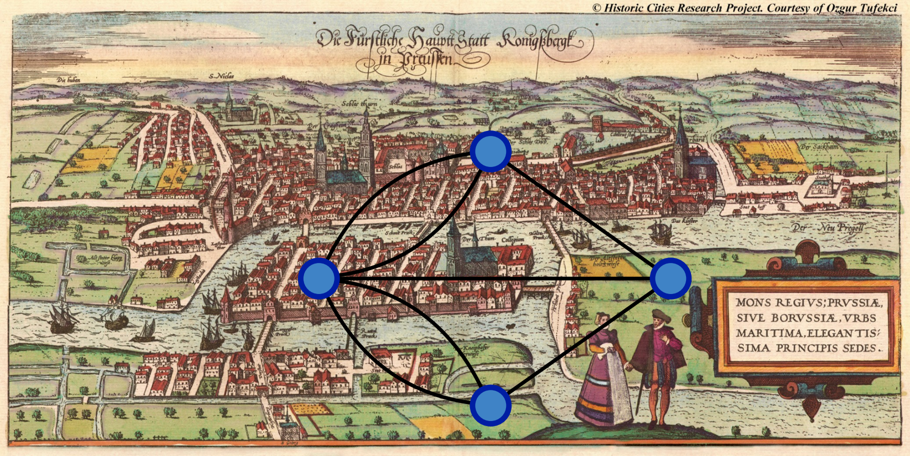


Creating Graphs

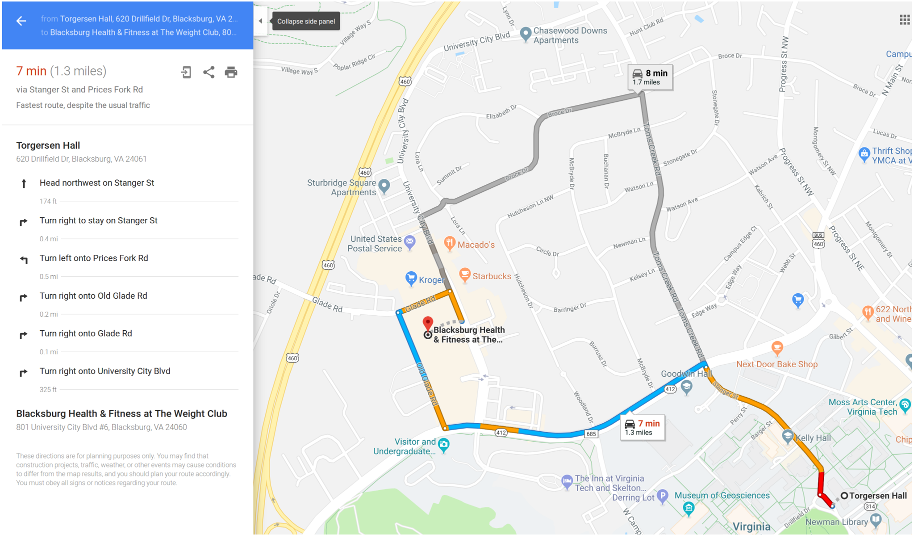
Node ≡ , Edge ≡

Creating Graphs

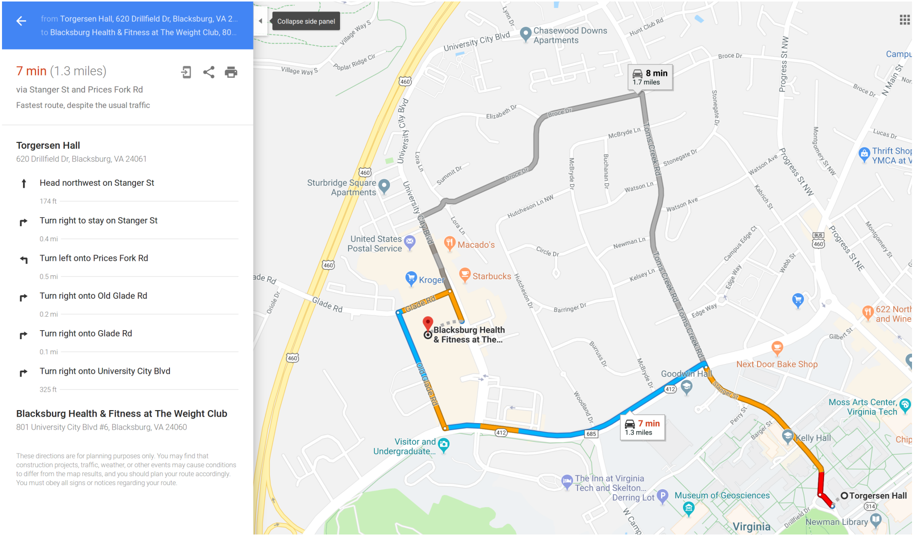
Node ≡ Land mass, Edge ≡ Bridge



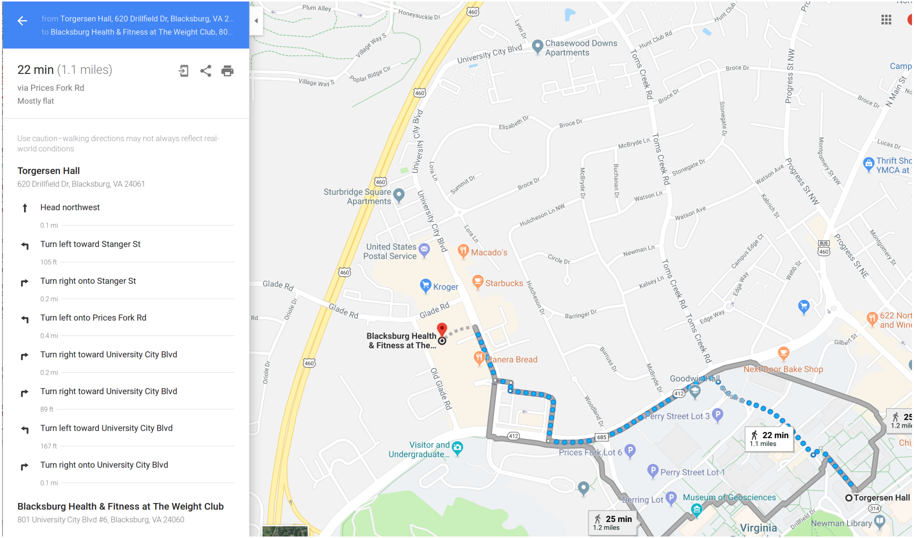
Node ≡ , Edge ≡


from Torgersen Hall, 620 Drillfield Dr, Blacksburg, VA 2...
to Blacksburg Health & Fitness at The Weight Club, 80...
Collapse side panel
7 min (1.3 miles)
via Stanger St and Prices Fork Rd
Fastest route, despite the usual traffic
Torgersen Hall
620 Drillfield Dr, Blacksburg, VA 24061
Head northwest on Stanger St
174 ft
Turn right to stay on Stanger St
0.4 mi
Turn left onto Prices Fork Rd
0.5 mi
Turn right onto Old Glade Rd
0.2 mi
Turn right onto Glade Rd
0.1 mi
Turn right onto University City Blvd
325 ft
Blacksburg Health & Fitness at The Weight Club
801 University City Blvd #6, Blacksburg, VA 24060
These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.
8 min
1.7 miles
7 min
1.3 miles
Blacksburg Health & Fitness at The...
Torgersen Hall
University City Blvd
Chasewood Downs Apartments
Sturbridge Square Apartments
United States Postal Service
Macado's
Kroger
Starbucks
Glade Rd
Old Glade Rd
Toms Creek Rd
Broce Dr
Stanger St
Goodwin Hall
Next Door Bake Shop
Moss Arts Center, Virginia Tech
Kelly Hall
Visitor and Undergraduate...
The Inn at Virginia Tech and Skelton...
Derring Lot
Museum of Geosciences
Newman Library
Virginia

Node $\equiv$ Intersection/Fork, Edge $\equiv$ Street segment



Node ≡ , Edge ≡


from Torgersen Hall, 620 Drillfield Dr, Blacksburg, VA 2...
to Blacksburg Health & Fitness at The Weight Club, 80...
22 min (1.1 miles)
via Prices Fork Rd
Mostly flat
Use caution–walking directions may not always reflect real-world conditions
Torgersen Hall
620 Drillfield Dr, Blacksburg, VA 24061
Head northwest
0.1 mi
Turn left toward Stanger St
105 ft
Turn right onto Stanger St
0.2 mi
Turn left onto Prices Fork Rd
0.4 mi
Turn right toward University City Blvd
0.2 mi
Turn right toward University City Blvd
89 ft
Turn left toward University City Blvd
167 ft
Turn right onto University City Blvd
0.1 mi
Blacksburg Health & Fitness at The Weight Club
801 University City Blvd #6, Blacksburg, VA 24060
Chasewood Downs Apartments
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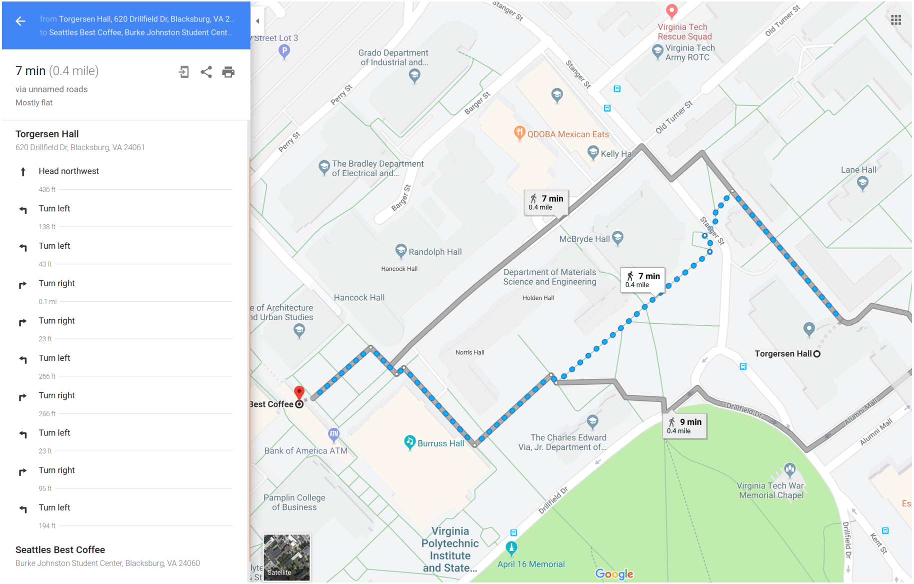
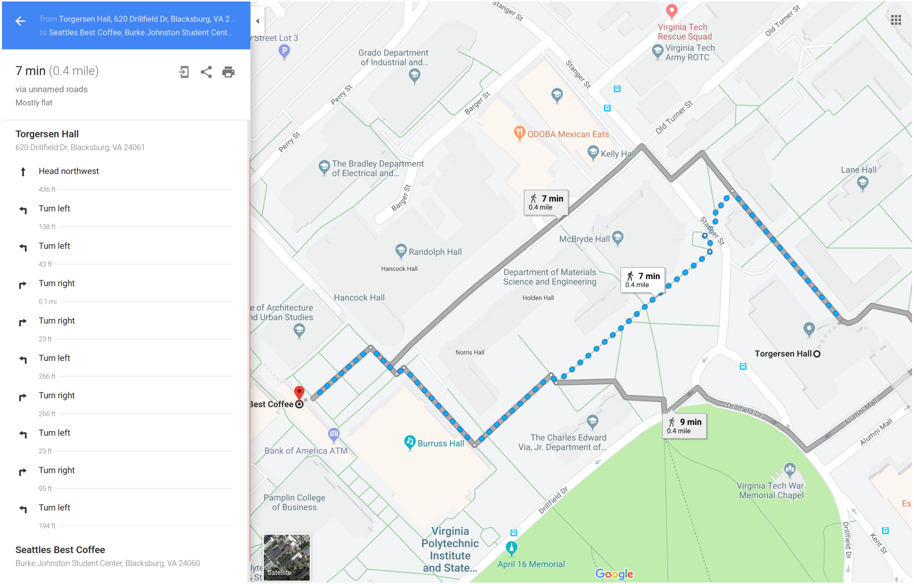
Virginia
22 min
1.1 miles
25 min
1.2 miles
University City Blvd
Toms Creek Rd
Progress St NW
Glade Rd
Prices Fork Rd

Node ≡ , Edge ≡


from Torgersen Hall, 620 Drillfield Dr, Blacksburg, VA 2...
to Seattles Best Coffee, Burke Johnston Student Cent...
7 min (0.4 mile)
via unnamed roads
Mostly flat
Torgersen Hall
620 Drillfield Dr, Blacksburg, VA 24061
Head northwest
436 ft
Turn left
138 ft
Turn left
43 ft
Turn right
0.1 mi
Turn right
23 ft
Turn left
266 ft
Turn right
266 ft
Turn left
23 ft
Turn right
95 ft
Turn left
194 ft
Seattles Best Coffee
Burke Johnston Student Center, Blacksburg, VA 24060
7 min
0.4 mile
7 min
0.4 mile
9 min
0.4 mile
Torgersen Hall
Best Coffee
Randolph Hall
Hancock Hall
McBryde Hall
Department of Materials Science and Engineering
Holden Hall
Norris Hall
Burruss Hall
Kelly Hall
QDOBA Mexican Eats
Lane Hall
Virginia Tech Rescue Squad
Virginia Tech Army ROTC
Grado Department of Industrial and...
The Bradley Department of Electrical and...
The Charles Edward Via, Jr. Department of...
Bank of America ATM
Pamplin College of Business
Virginia Polytechnic Institute and State...
April 16 Memorial
Virginia Tech War Memorial Chapel
Drillfield Dr
Alumni Mall
Stanger St
Barger St
Perry St
Old Turner St
Kent St
Satellite
Google

Node ≡ "Intersection", Edge ≡ Walkway/Unnamed road



How Do We Create Street Maps?

How Google Builds Its Maps—and What It Means for the Future of Everything

An exclusive look inside Ground Truth, the secretive program to build the world's best accurate maps

ALEXIS C. MADRIGAL | SEP 6, 2012 | TECHNOLOGY

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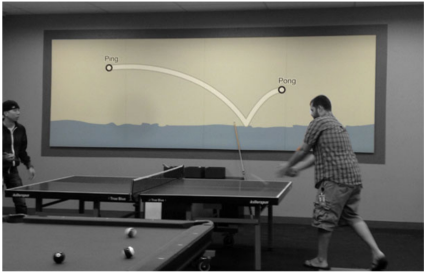


How Do We Create Street Maps?

I was slated to meet with Gupta and the engineering ringleader on his team, former NASA engineer Michael Weiss-Malik, who'd spent his 20 percent time working on Google Mars, and Nick Volmar, an "operator" who actually massages map data.

"So you want to make a map," Weiss-Malik tells me as we sit down in front of a massive monitor. "There are a couple of steps. You acquire data through partners. You do a bunch of engineering on that data to get it into the right format and conflate it with other sources of data, and then you do a bunch of operations, which is what this tool is about, to hand massage the data. And out the other end pops something that is higher quality than the sum of its parts."

This is what they started out with, the TIGER data from the US Census Bureau (though the base layer could and does come from a variety of sources in different countries).

How Do We Create Street Maps?

Census.gov

United States Census Bureau

25th Anniversary of TIGER

TIGER is celebrating its 25th anniversary. The **Topologically Integrated Geographic Encoding and Referencing** database—the first nationwide digital map of roads, boundaries, and other features—was initially created for the 1990 Census to modernize the once-a-decade head count. However, its impact went well beyond its initial purpose by offering common map data in electronic form that powers the geographic information system (GIS) industry today. Through its TIGER/Line products, the Census Bureau has provided the common geospatial framework for use in linking statistical and other data in GIS.

The idea for TIGER developed within the Census Bureau. In the 1970s mathematicians, geographers, and software developers designed a spatial data handling system that resembled one big spreadsheet. Custom-built solutions were the norm for most GIS software companies in the two decades leading up to TIGER's release. TIGER was like a giant

How Do We Create Street Maps?

How Do We Create Street Maps?

OpenStreetMap powers map data on thousands of web sites, mobile apps, and hardware devices

OpenStreetMap is built by a community of mappers that contribute and maintain data about roads, trails, cafés, railway stations, and much more, all over the world.

Local Knowledge

OpenStreetMap emphasizes local knowledge. Contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date.

Community Driven

OpenStreetMap's community is diverse, passionate, and growing every day. Our contributors include enthusiast mappers, GIS professionals, engineers running the OSM servers, humanitarians mapping disaster-affected areas, and many more. To learn more about the community, see the OpenStreetMap Blog, user diaries, community blogs, and the OSM Foundation website.

Open Data

OpenStreetMap is *open data*: you are free to use it for any purpose as long as you credit OpenStreetMap and its contributors. If you alter or build upon the data in certain ways, you may distribute the result only under the same licence. See the Copyright and License page for details.

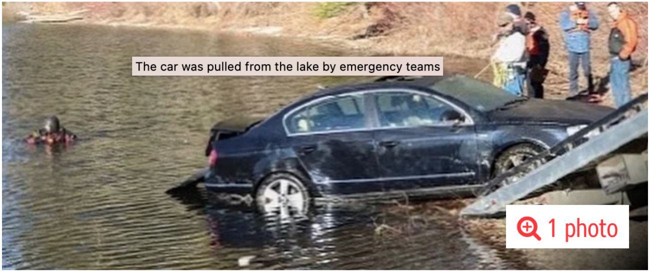
How Do We Correct Street Maps?

Driver Claims GPS Navigation Sent Him in a Lake, So He Obeyed

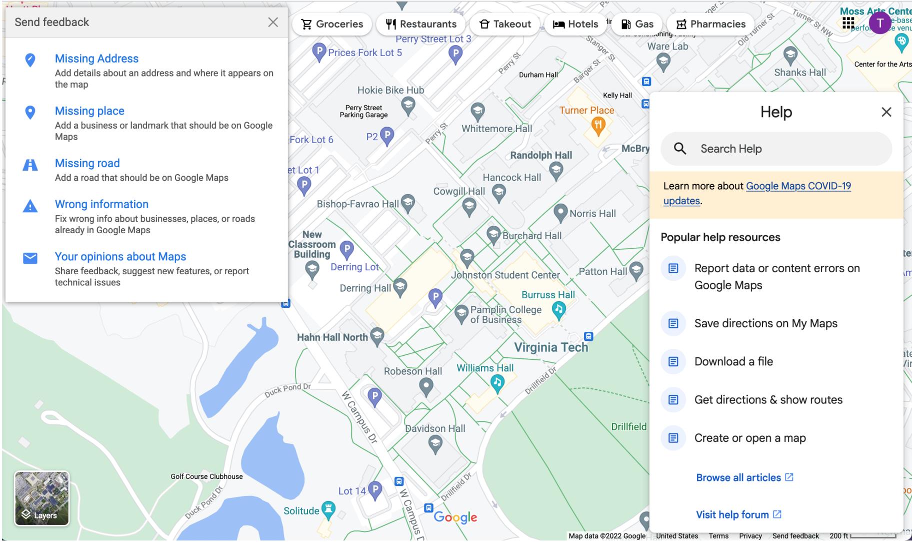
Home > News > U-turn

29 Mar 2021, 09:07 UTC · by **Bogdan Popa**

If you still needed more evidence that always trusting a navigation app is a bad thing, here's the story of an American driver who ended up with his car in Buffumville Lake in Charlton after blindly following GPS instructions.



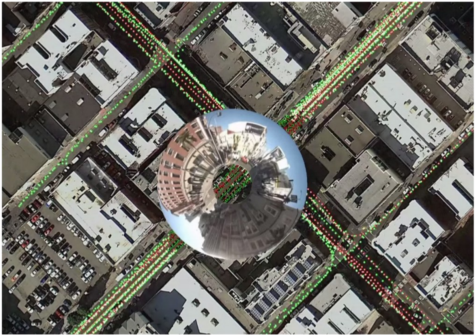
How Do We Correct Street Maps?



How Do We Correct Street Maps?

GREG MILLER SCIENCE 12.08.14 06:45 AM

THE HUGE, UNSEEN OPERATION BEHIND THE ACCURACY OF GOOGLE MAPS



Inside Atlas, Google's map-editing program, operators can see where Street View cameras have captured images (colored dots), and zoom in with a spyglass tool. GOOGLE MAPS

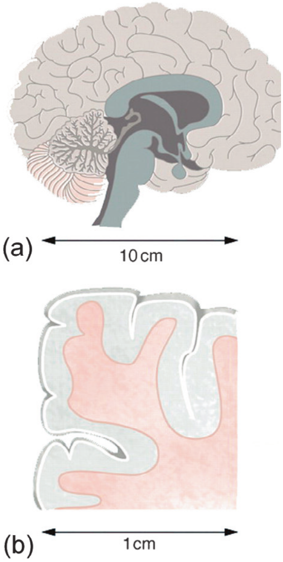
Nodes and Edges

- Nodes and edges are elemental building blocks of networks.

What are the nodes and edges of brain graphs?

- Multiscale architecture of brain makes the answer challenging.
- There is no single, privileged scale for the analysis of brain networks.
- No single technology that can measure brain networks over all biologically relevant scales of space or time.

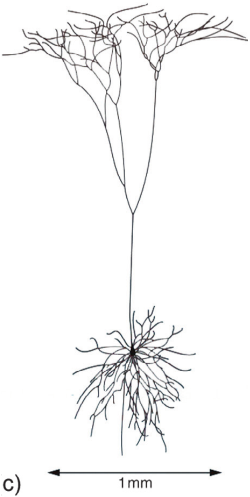
Multiscale Organisation of Brain Anatomy



Broad divisions: cortical lobes, cytoarchitectural areas

Neurons aggregate into columns, layers, and cell groups

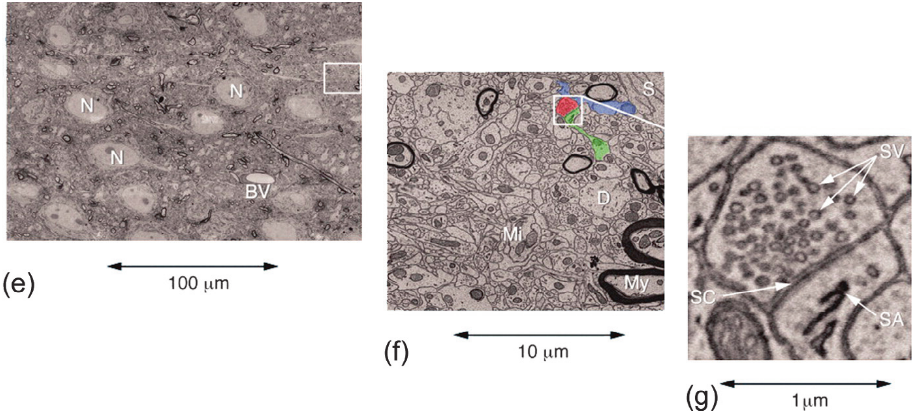
Multiscale Organisation of Brain Anatomy



Neuronal processes such as dendritic trees and axons

Structure of individual fibers and dendritic spines

Multiscale Organisation of Brain Anatomy



N: neuron, BV: blood vessel,
S: soma (cell body), Mi: mitochondria, My: myelinated axon, D: dendrite,
Blue: glial processes, Red: presynaptic terminal, Green: dendritic spines,
SV: synaptic vesicles, SC: synaptic cleft, SA: spine apparatus

Three Spatial Scales

- *Microscopic scale*: properties that are too small to resolve with the naked eye.
  - Require the use of microscopic techniques for visualization.
  - Scale that is synonymous with networks reconstructed at the level of individual neurons and synapses.

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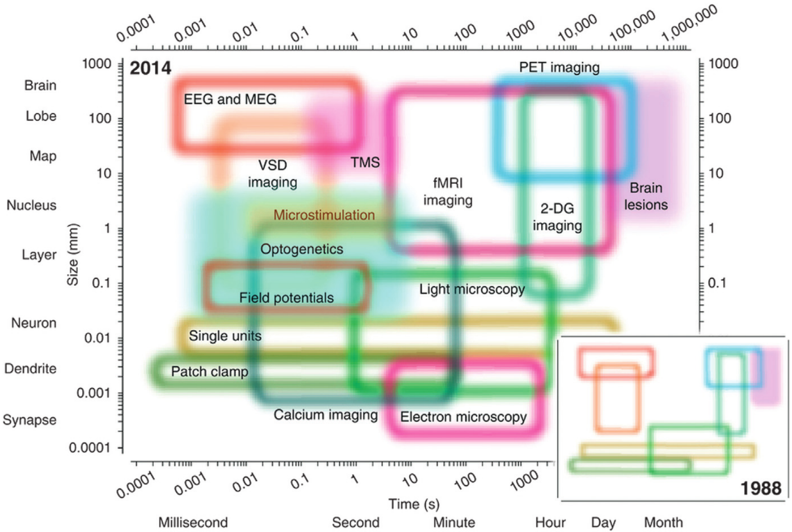
- Techniques used at each scale constrain the way in which nodes and edges are defined.

Three Types of Connectivity

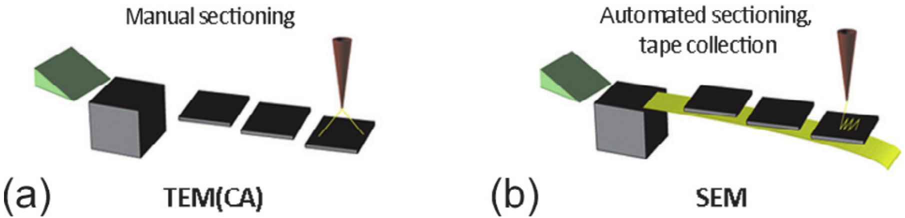
- *Structural*: anatomical connections between neural elements
  - Example: axons and synapses between neurons at the microscale.
  - Example: Large-scale fiber bundles that link cortical areas and subcortical nuclei at meso- and macroscales.
  - Measured using techniques such as electron microscopy (micro), axonal tract-tracing (meso), and diffusion MRI (macro).
- *Functional*: statistical dependence between physiological recordings that have been acquired from distinct neural elements.
  - Example: Correlation between spiking output of two neurons.
  - Measured by mathematical definitions of correlations.
- *Effective*: direct, causal influence that one neural element exerts another's activity. Tries to capture minimum neuronal circuit model that can reproduce observed signal dependencies.

Spatiotemporal Resolution of Measurement Techniques



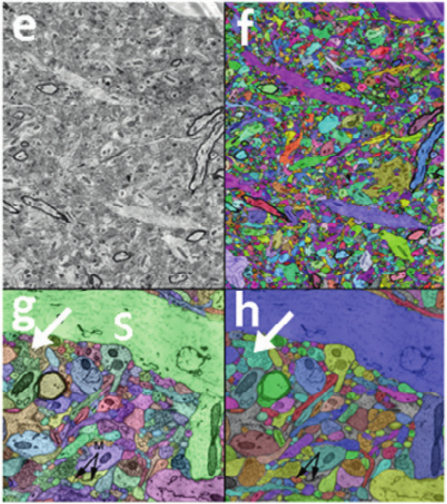
Open areas: measurement, filled areas: perturbation

Structural Connectivity at the Microscale



- Transmission electron microscopy (TEM): a beam of electrons is transmitted through a specimen to form an image.
- Scanning electron microscopy (SEM): produce images of a sample by scanning the surface with a focused beam of electrons.

Structural Connectivity at the Microscale



Mouse cortex section: 40 μm $\times$ 20 μm $\times$ 30 nm.

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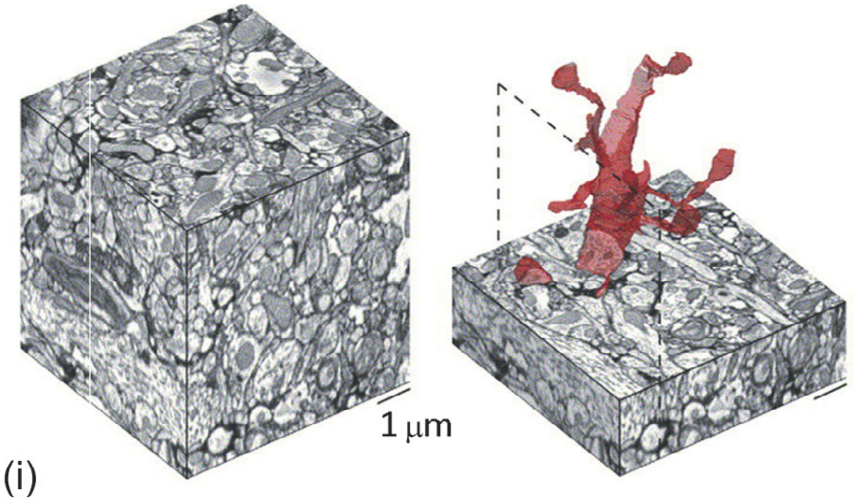

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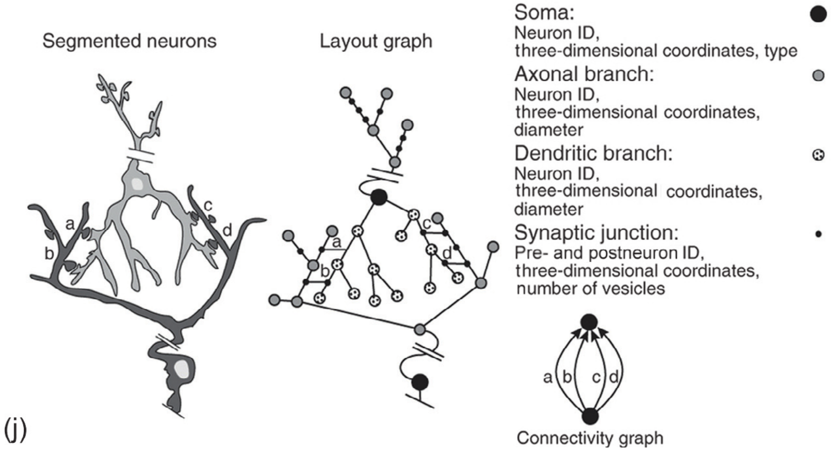

Graphs from Microscale Structural Connectivity

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- Reconstructing connectomes in this manner is computationally demanding, time-consuming, and labor intensive.
  - One cubic millimeter of rat cortex imaged with a resolution of a few nanometers will create 2PB of data.
  - A complete atlas of rat cortex (vol $\approx$ 500 cubic mm) will require around 1 EB (1000 PB).
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  - Accurate segmentation and annotation is difficult and tedious.

Functional Connectivity at the Microscale

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- Measure neuronal activity over time.
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  - Classic method: Insert electrodes distinct parts of the brain to record the spiking activity of either individual or multiple cells.
  - Multi-electrode arrays: neurons cultured *in vitro*, i.e., in the lab.
  - Calcium imaging can map neuronal interactions across large distances with cellular resolution.
    - ⋆ Measures intracellular calcium levels by introducing specific molecules.
    - ⋆ Can sample only a restricted, superficial patch of cortex at any time.
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- Define how to compute similarity or statistical dependence of two time series.
  - Pearson's correlation coefficient. Read Box 2.2 on pages 50–51.
  - Rank correlation coefficients.
  - Mutual information.

From Microscale to Mesoscale

- Microscale connectomics
  - Pro: offers unparalleled precision for resolving synaptic connectivity and spiking activity of individual neurons
  - Con: Techniques are not scalable to large-scale neural systems.
  - Con: High plasticity of synaptic connectivity makes it difficult to distinguish stable characteristics of neuronal networks from more transient features.

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- Mesoscale connectomics
  - Pro: Can smooth out some variability.
  - Pro: Offers a more robust means for characterizing time-invariant aspects of brain architecture.
  - Con: Not at the level of individual neurons.
  - Con: Depends on the parcellation.

Defining Nodes at the Mesoscale

- Goal is to map connectivity between neuronal populations or cell assemblies, rather than individual neurons.
- Exploit aggregation of neurons aggregate into populations that perform the same or related functions and are spatially proximal.
- Treat each volume as a node.
  - A volume may contain thousands or millions of cells.
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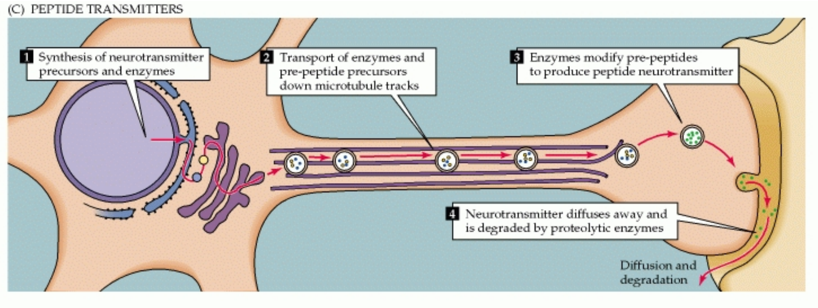
- No gold standard for defining nodes; use approximations based on cytoarchitecture and anatomical landmarks.
- Coarse approach to defining nodes results in the loss of information.
- Counterbalanced by an improved ability to map network structure over long distances.

Tracers for Structural Connectivity at the Mesoscale

- Invasive tract tracing is the main technique.
- A fluorescent dye or other tracer molecule injected into a specific part of the brain.
- Cellular membranes are permeable to these tracers.
- Once the tracer inside the cell, active axonal transport transfers it from the soma to peripheral axon terminals.
- After the tracer has had sufficient time to fill the entire extent, sacrifice the animal, dissect the brain, and determine sites of tracer uptake.

Types of Tracers



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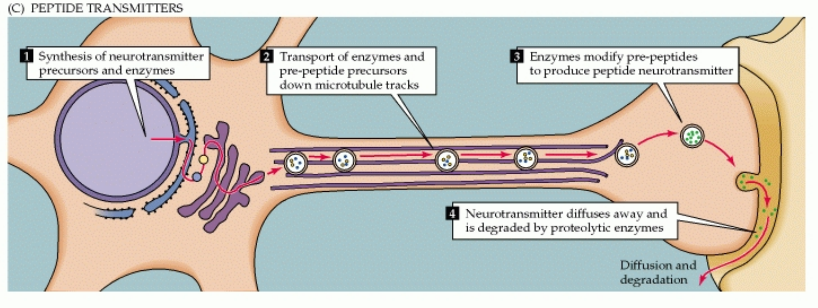

- Direction of transport distinguishes tracers.
- *Anterograde tracers*: transported from the cell body to the axon terminal; used to map the efferent projection sites of an injected area.
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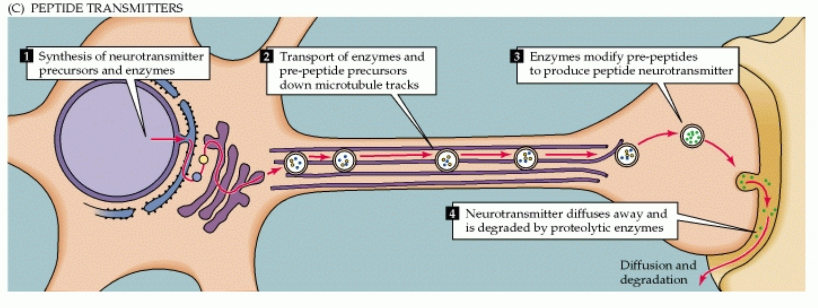
Types of Tracers



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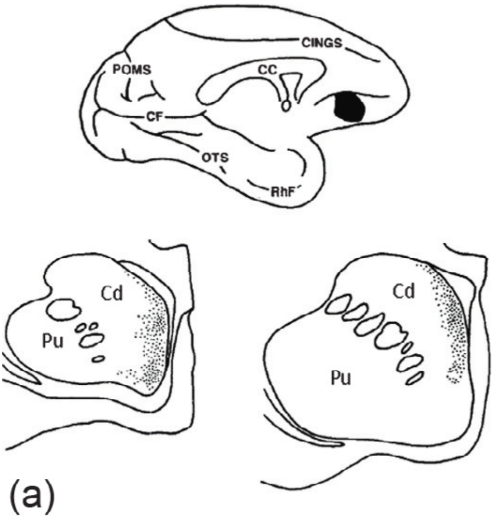
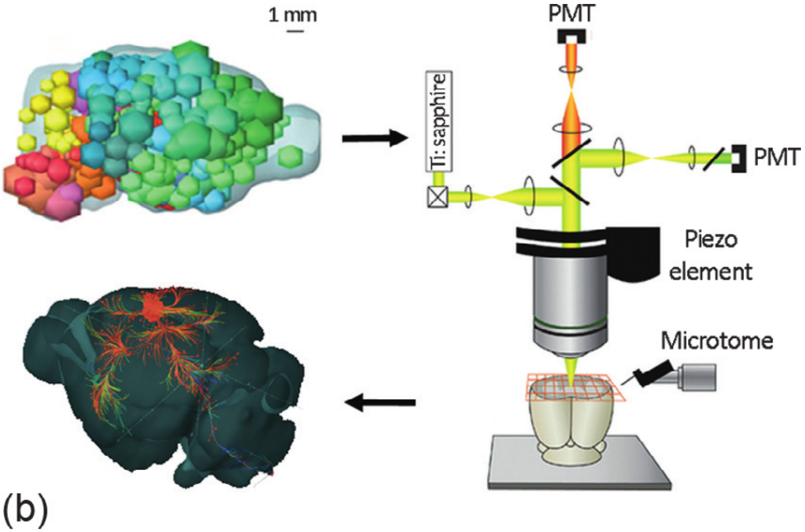
- Viral tracers can cross synaptic junctions, allowing the mapping of polysynaptic pathways.

Structural Connectivity at the Mesoscale: Mouse



Results from a traditional tract tracing experiment

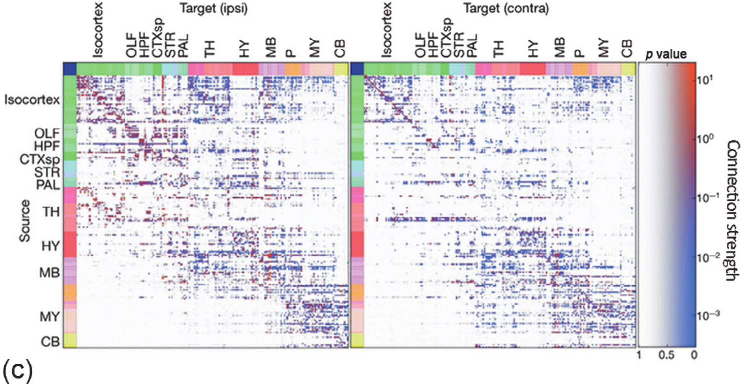
Structural Connectivity at the Mesoscale: Mouse



Modern experimental setup for whole-brain connectivity mapping

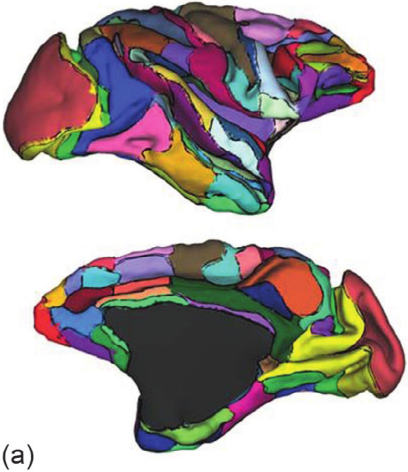
469 distinct tracer experiments

Structural Connectivity at the Mesoscale: Mouse



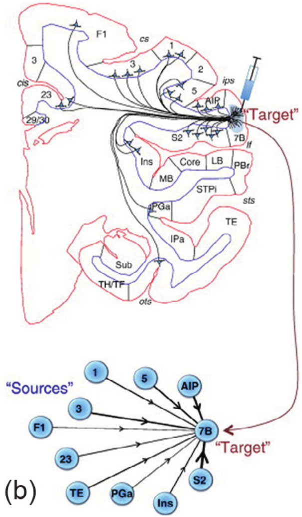
Example of connectivity matrix.
Edge weights range over four orders of magnitude.

Structural Connectivity at the Mesoscale: Macaque



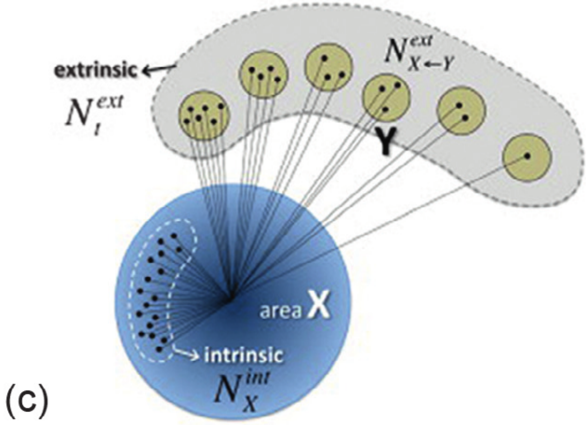
Parcellate the macaque cortex into 91 areas, defined according to cytoarchitecture and sulco-gyral landmarks.

Structural Connectivity at the Mesoscale: Macaque



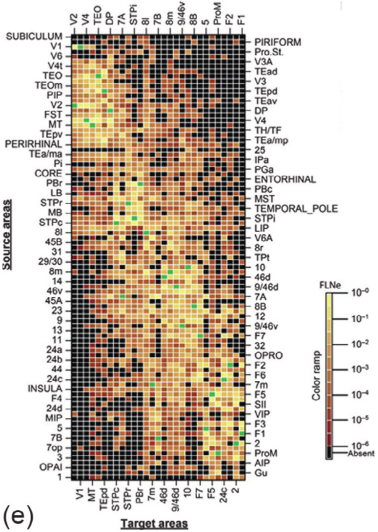
Use retrograde tract tracing. Determine edges coming into node representing area of injection from "labelled" nodes representing neurons that the tracer reaches.

Structural Connectivity at the Mesoscale: Macaque



Injection is at X: $w(Y, X) = \frac{\text{number of neurons labelled in } Y}{\text{total number of labelled neurons}}$

Structural Connectivity at the Mesoscale: Macaque



Example of connectivity matrix.

Edge weights range over six orders of magnitude.

Functional Connectivity at the Mesoscale

Please read Chapter 2.2.2 of the textbook.

From Mesoscale to Macroscale

- Experimental methods we have discussed so far for measuring brain connectivity are invasive.
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  - Con: Difficult to apply across the entire brain, particularly in larger animals and humans.

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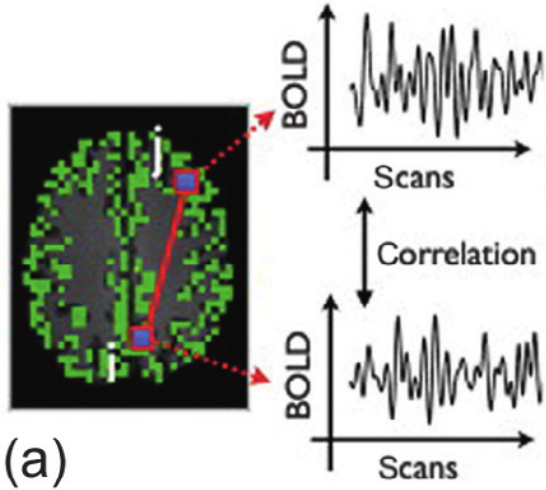
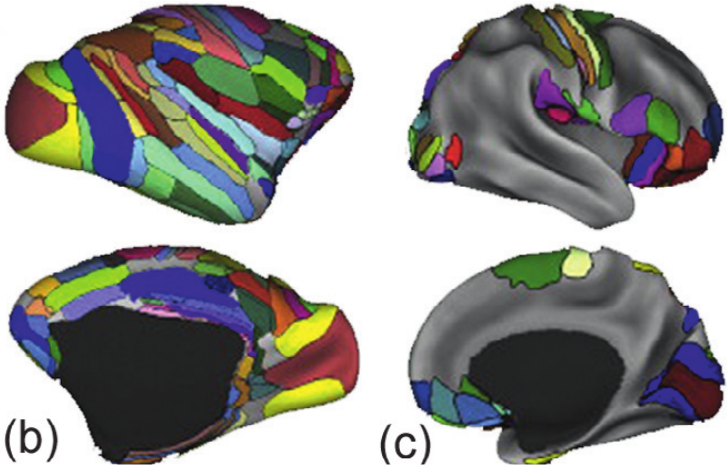
- Coarse spatial resolution means
  - We must aggregate measurements over ever-larger populations of neurons, axons, and synapses.
  - Reduces precision of node and edge definition.

Defining Nodes at Macroscale



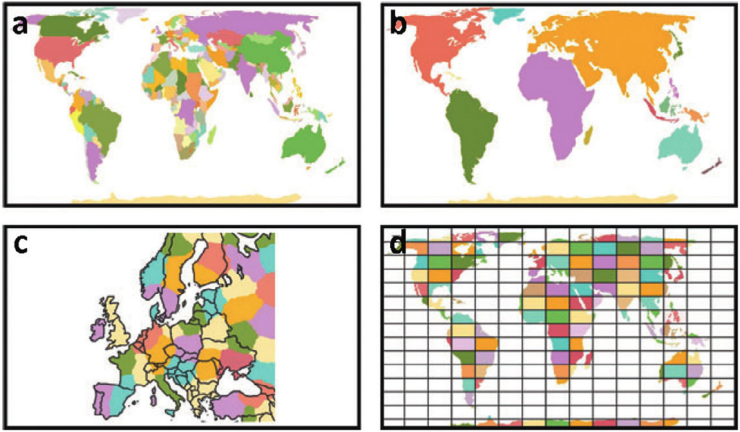
Each voxel is a node. Correlation between measurements for node pairs defines edges.

Defining Nodes at Macroscale



Cytoarchitectural atlases mapped to standard stereotactic space. (b) Macaque brain. (c) Human brain.

Parcellation Can Affect Network Properties



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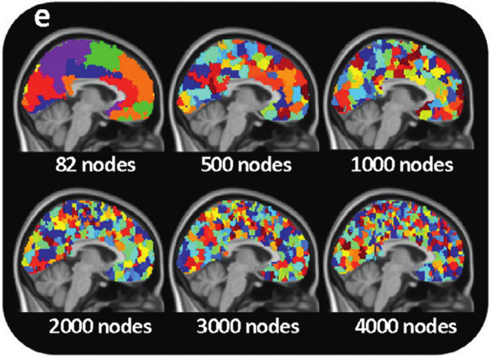
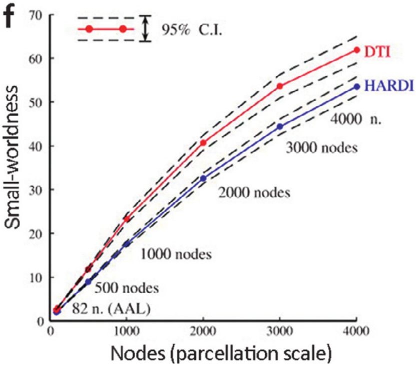
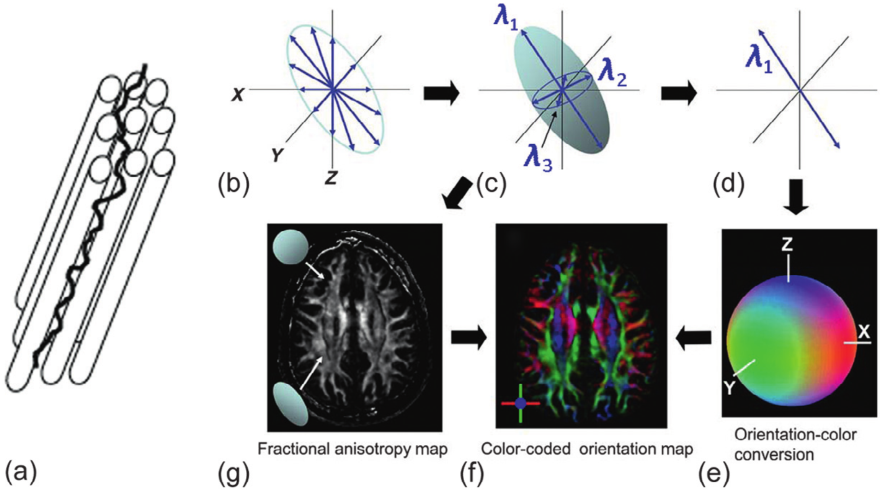




Structural Connectivity at the Macroscale



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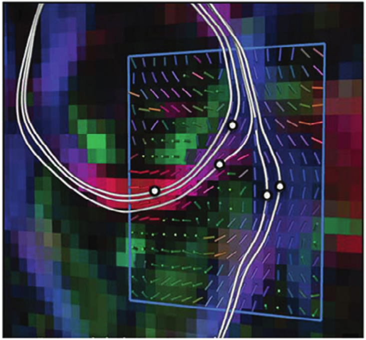
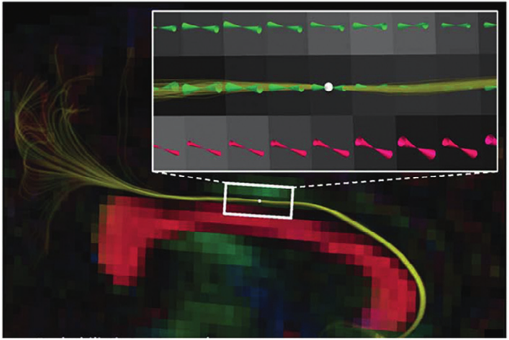
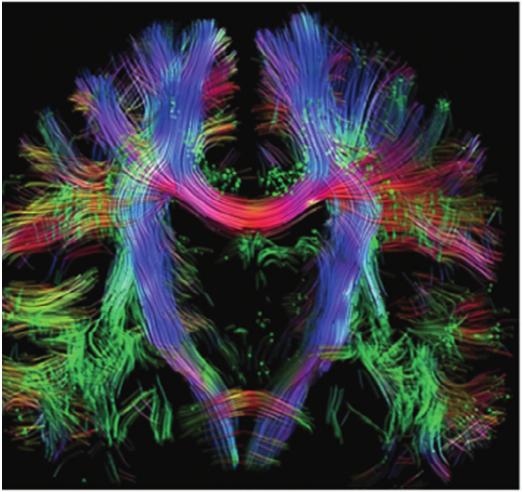


(h) Deterministic



(i) Probabilistic

Structural Connectivity at the Macroscale



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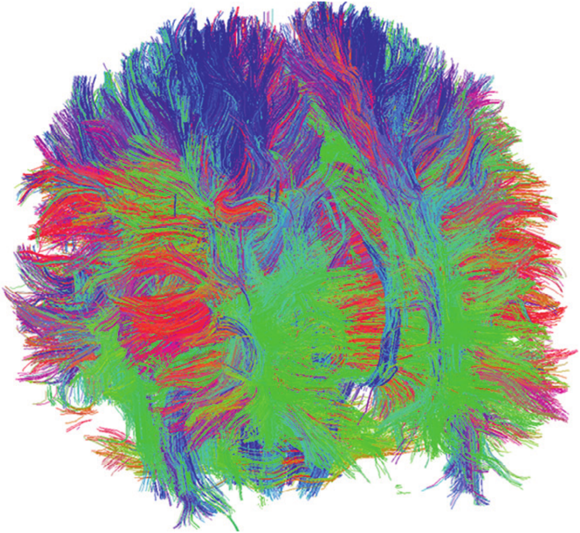
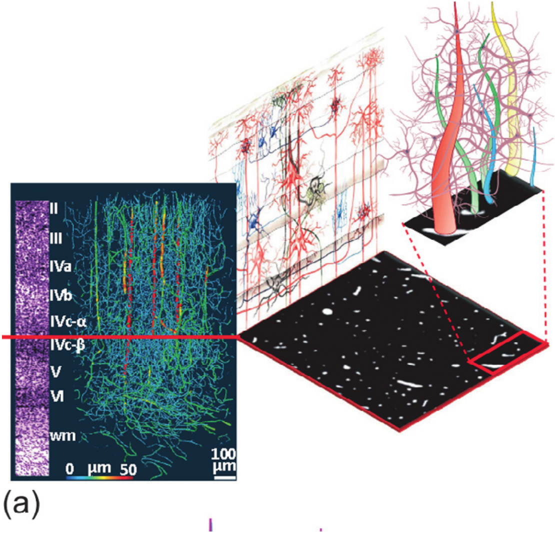


Functional Magnetic Resonance Imaging

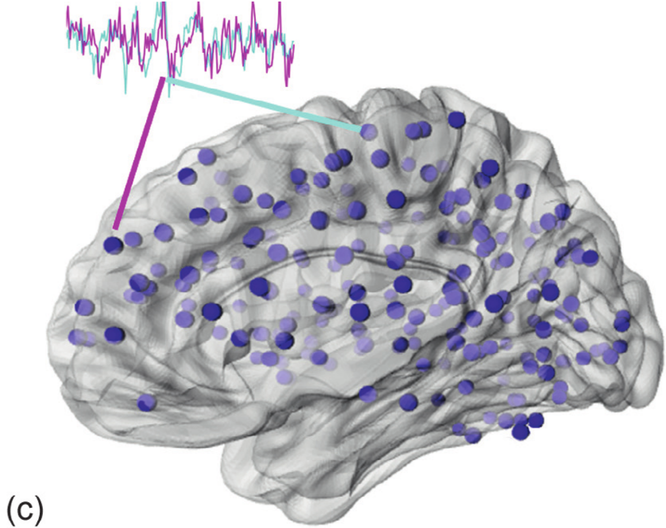
fMRI - How it Works and What it's Good For, Video, 6:41"

Functional Connectivity at the Macroscale



(a)

Functional Connectivity at the Macroscale



Functional Connectivity at the Macroscale