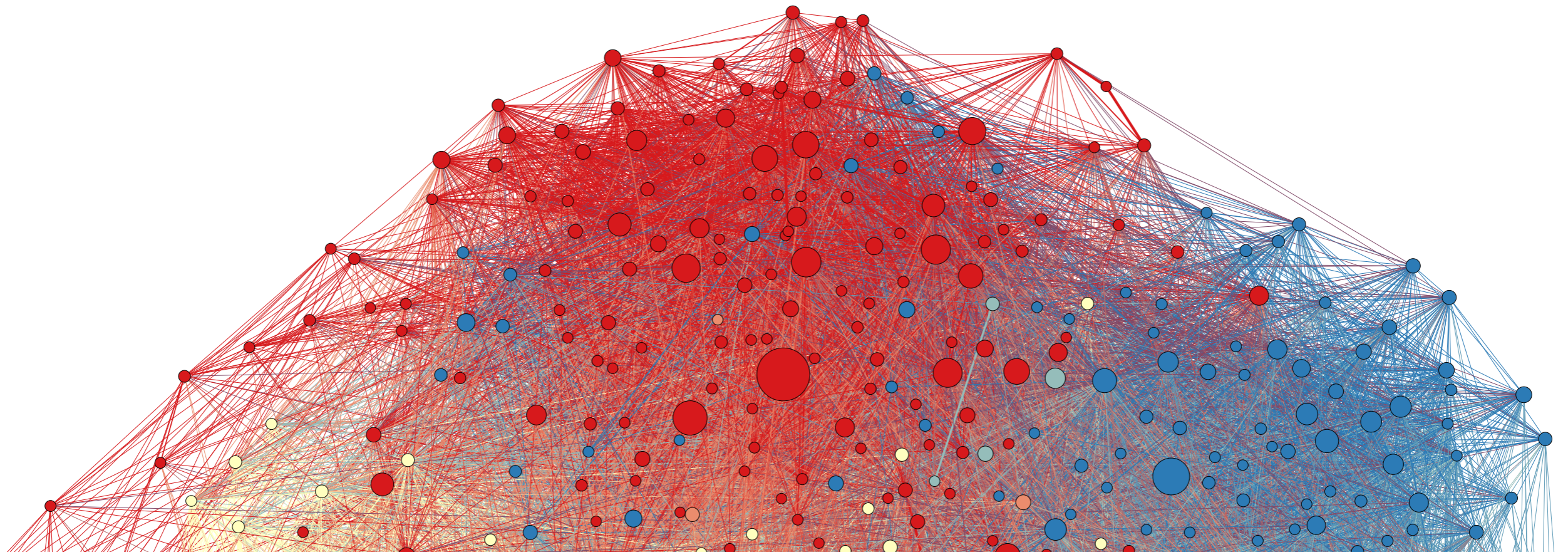


# Writers, Designers, and Software Developers: Network-Based Measures of Worker Skills

Kate Anderson




# Why Think about Skills?

The workplace is changing:

- Automation is affecting entirely new sectors of the workforce:
  - Accountants
  - Librarians
  - Office Workers
  - Travel Agents
  - Customer Service
  - Programmers
  - Health Care
  - Lawyers

**Since 1990, library and administrative jobs have declined by 40%**

**This is a loss of jobs on the scale of the steel industry, but much less visible!**





# The Changing Labor Market

The labor market is constantly adjusting to new technology.

People retrain into jobs that use some or all of their skills

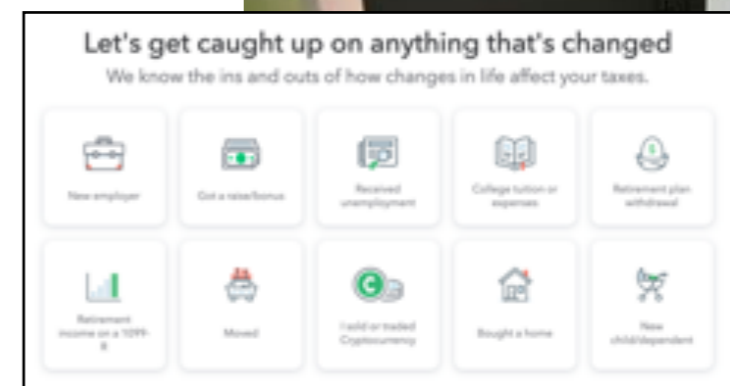
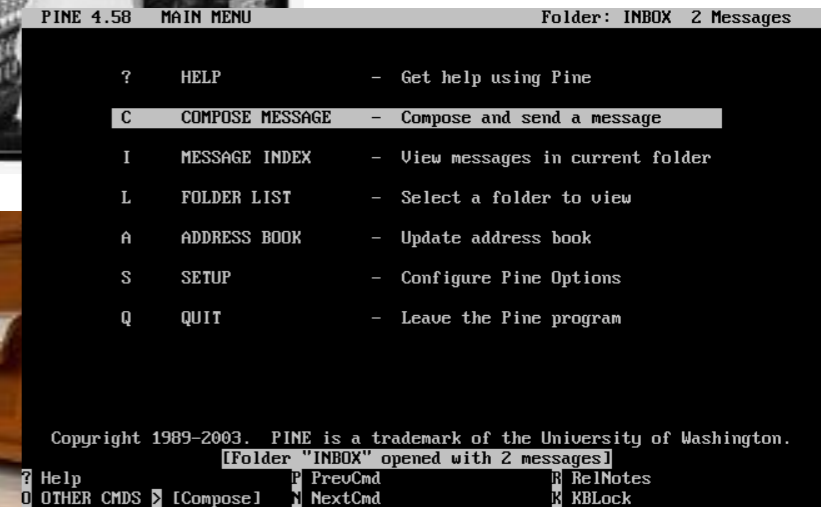
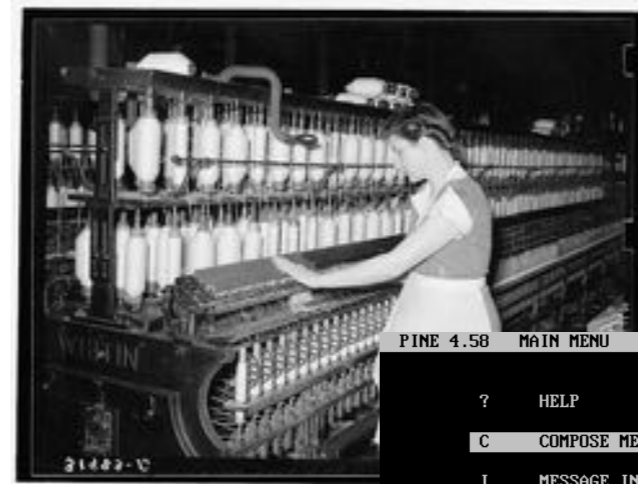
Librarian → CS, Teaching, Communications, IT

Admin → Marketing

Travel Agent → Customer Service

As more jobs are changed or eliminated, this becomes more pressing

What will young lawyers retrain to do?



# The Changing Labor Market

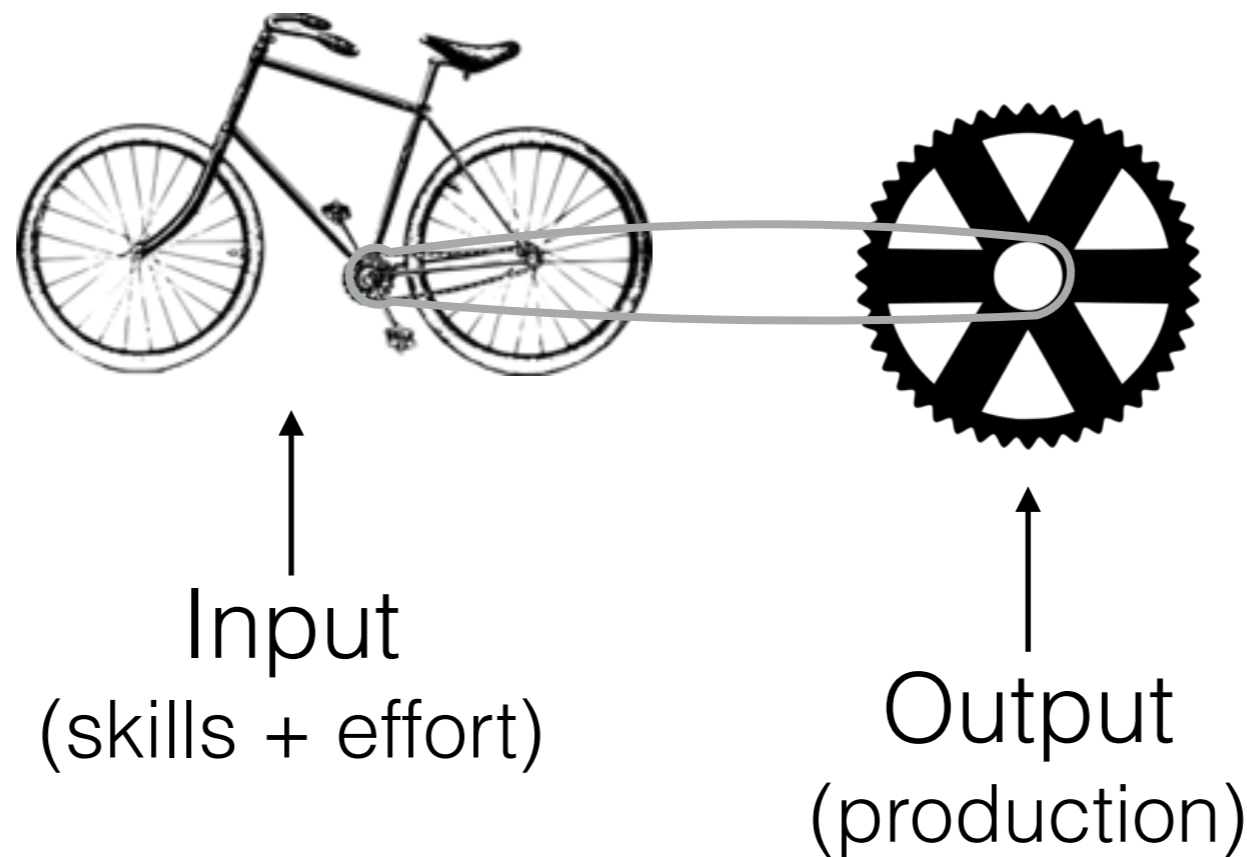
That raises important questions:

- How do skills translate into wages?
- Which combinations of skills are endangered?
  - Which of those skills are transferable to other occupations?
  - What skills should workers acquire to bolster their job prospects in the AI economy?
- How can the strengths of AI be used to *complement* human skills?



# Economic Models of Skills and Production

Economists usually think about skills in terms of production:



The value that people bring to production is called *human capital*

# Measures of Human Capital

Traditional notions of human capital are motivated by manufacturing

One-dimensional skill level:

- Mankiw, Romer, and Weil (1992):
- Gibbons and Katz (1991)

Two types/occupations:

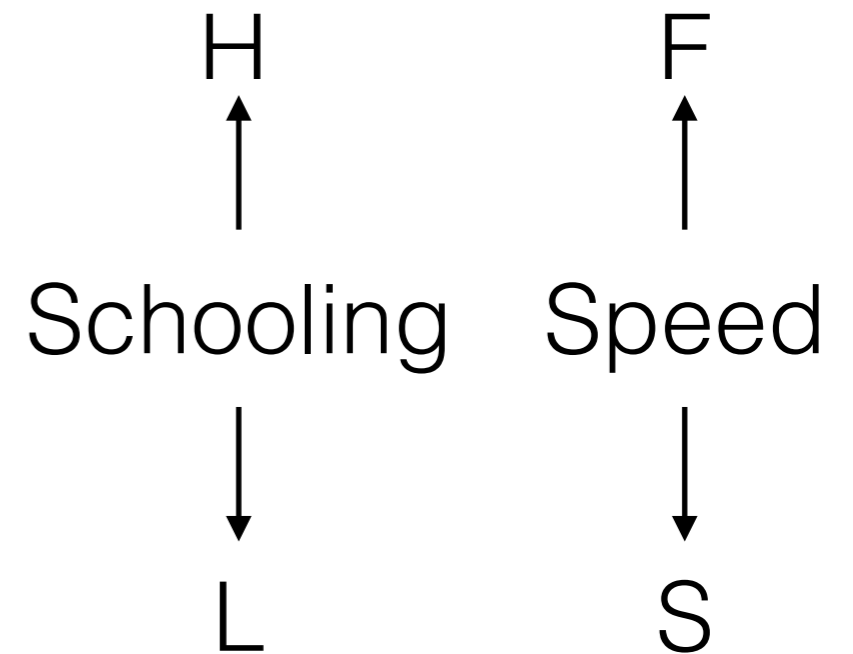
- Roy Model (1951)



hunter

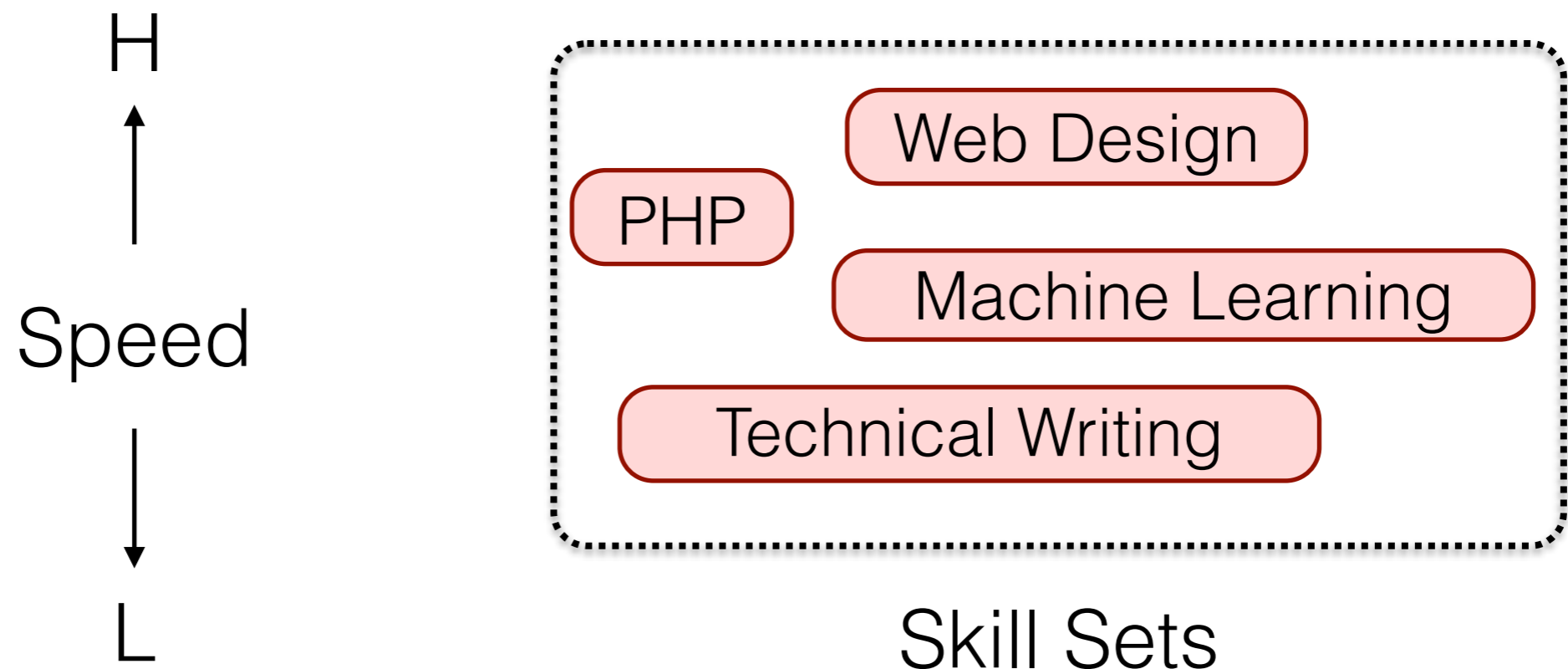


fisherman



# Skills and Production

But human capital is much different in knowledge-based production: skill *combinations* become more important





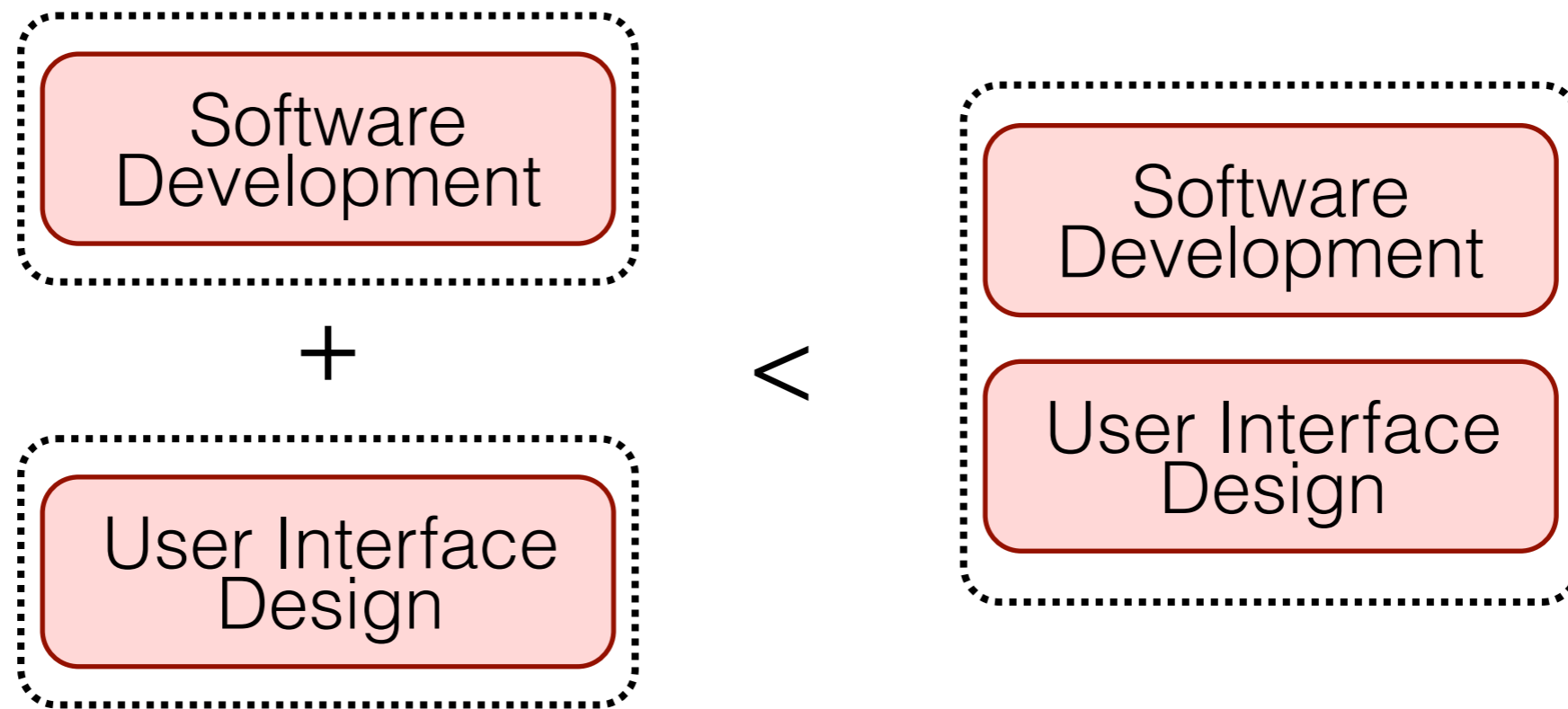
# Multi-dimensional Human Capital

Interest in a more nuanced view of human capital:

- Leung and Ng (2014), Leung (2014): boundary spanning between job categories
- Heckman et al (2006): Cognitive and Non-cognitive skills
- Lazear (2005): breadth of experience by number of roles in employment history
- Adamic et al (2010): focus, with skills = topics
- Autor and Handel (2009): O\*NET categorizing occupations by required skills
- Psychology and OBT literatures: team-level diversity related to performance/ productivity with skills = assessment-based measures

# Complex Human Capital

A crucial factor in multi-dimensional human capital is that some skills work together: they are more valuable together than they are apart

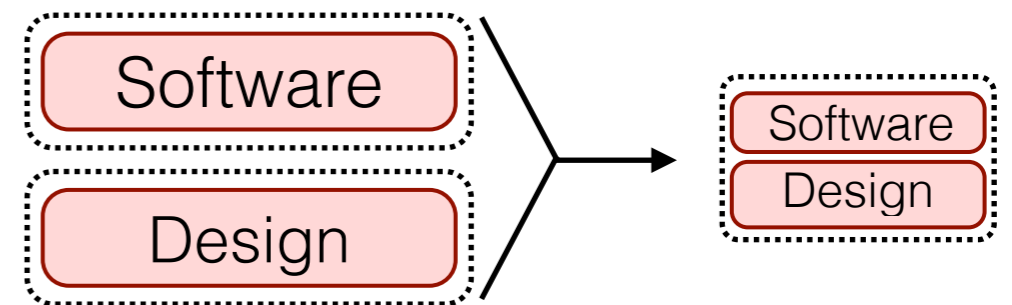


These synergies between skills often distinguish workers in the labor market

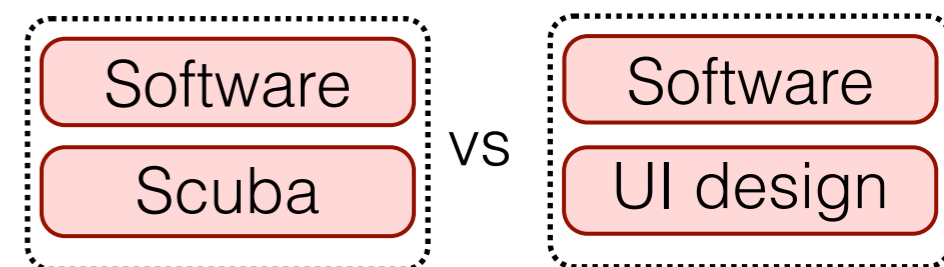
# Complex Human Capital

But this makes determining the potential value of a worker *much* more complicated

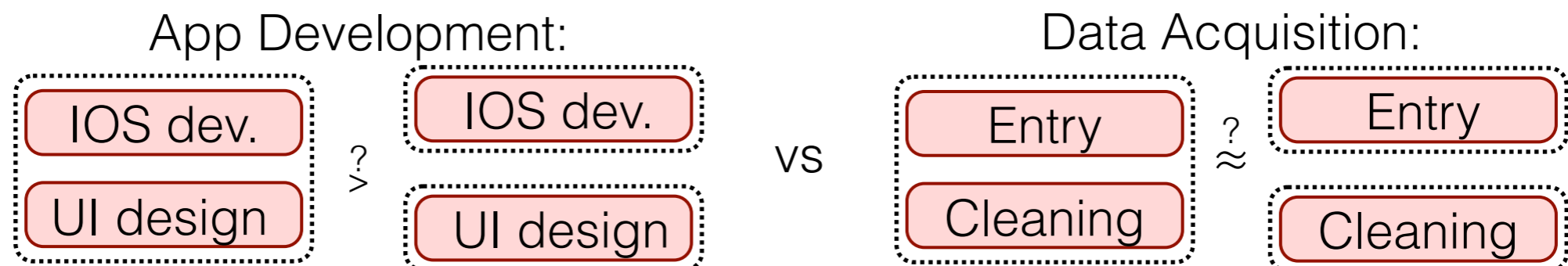
- Skills that are common individually may be rare in combination



- Some skills are more valuable in combination and others are not



- Some tasks are more “separable” than others

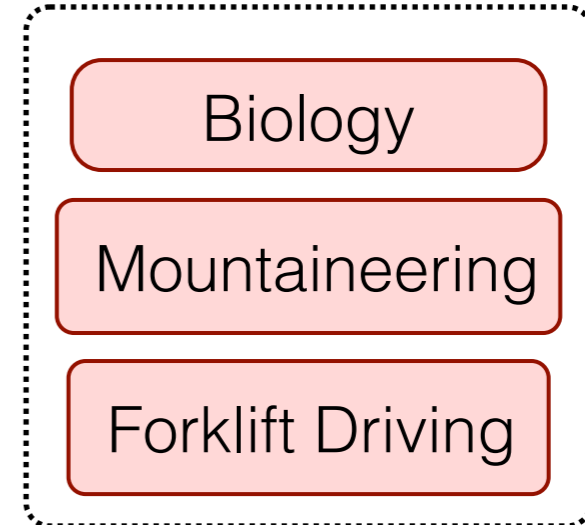
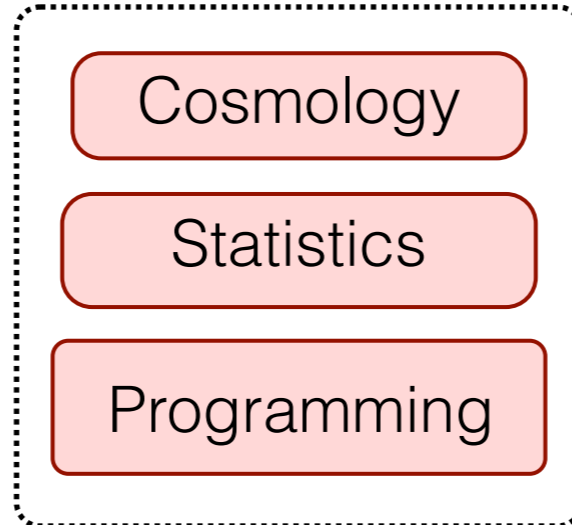




# Skill Sets and Productivity

So we cant assign prices to individual skills

- The value of adding a skill to a workers skill set depends on the skills she already has
- The value of a combination may be more than the sum of its parts



# Complex Human Capital

So does this make a difference in the labor market?

Yes!

Both in theory and in practice!

# Wages with Skill Combinations

A labor market:

Workers  $I = \{1, 2, 3 \dots N\}$

Each endowed with a skill set,  $A_i$  drawn from  $S = \{s_1 \dots s_K\}$

Skill sets distributed according to  $\delta : \mathcal{P}(S) \rightarrow [0, 1]$

Workers compete for jobs:  $\mu = \{\mu_1 \dots \mu_M\}$

A job requires skills  $\mu_j \subseteq S$

Job requirements distributed according to  $\sigma : \mathcal{P}(S) \rightarrow [0, 1]$

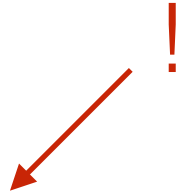
With some additional assumptions:

$$E [w(A)] = \sum_{C \subseteq A} \frac{\sigma(C)}{\sum_{D \subseteq S} \delta(C \cup D)}$$



# Wages with Skill Combinations

$$E [w(\{a\})] = \frac{\sigma(\{a\})}{\delta(\{a\})}$$

$$E [w(\{a, b\})] = \frac{\sigma(\{a\})}{\delta(\{a\})} + \frac{\sigma(\{b\})}{\delta(\{b\})} + \frac{\sigma(\{a, b\})}{\delta(\{a, b\})}$$


When there is no demand for skills in combination, wages are additive  $E [w(A \cup B)] = E [w(A)] + E [w(B)]$

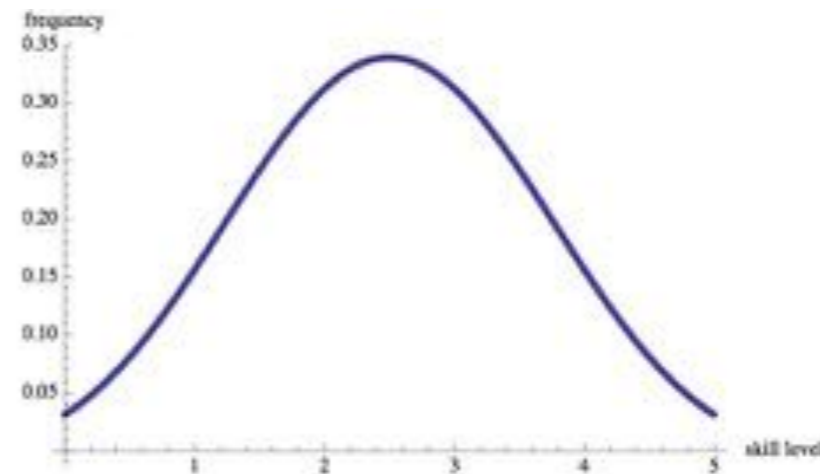
When there is, wages are super additive:

$$E [w(A \cup B)] > E [w(A)] + E [w(B)]$$

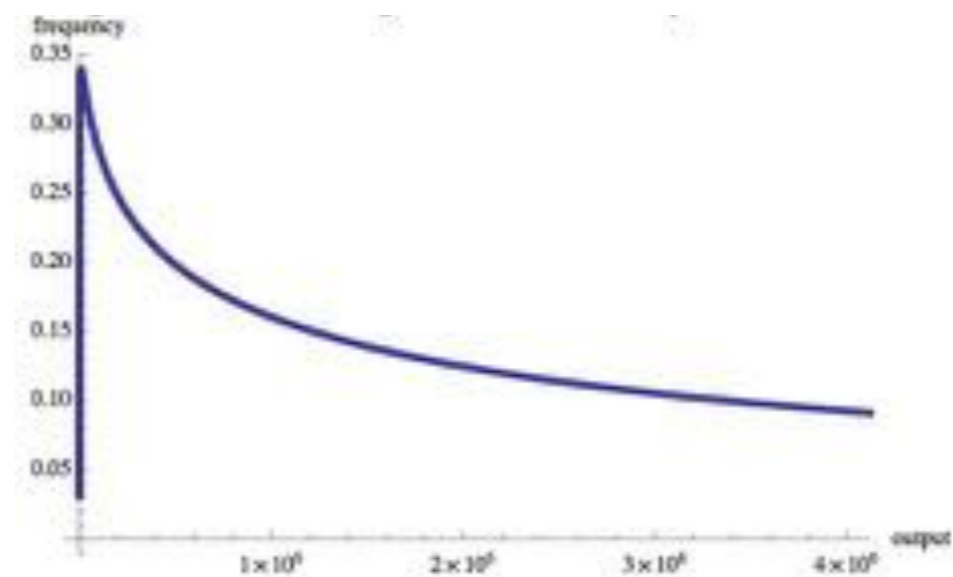
# Wages with Skill Combinations

Suppose skills are distributed to workers independently with equal probability

When skills are only used individually, wages mirror the distribution of skills



When jobs require combinations of skills, skill differences are exaggerated



Considering skill combinations should help us understand more variation in wages

# Wages with Skill Combinations

But we also cant think about all possible interactions—  
the problem is too big!

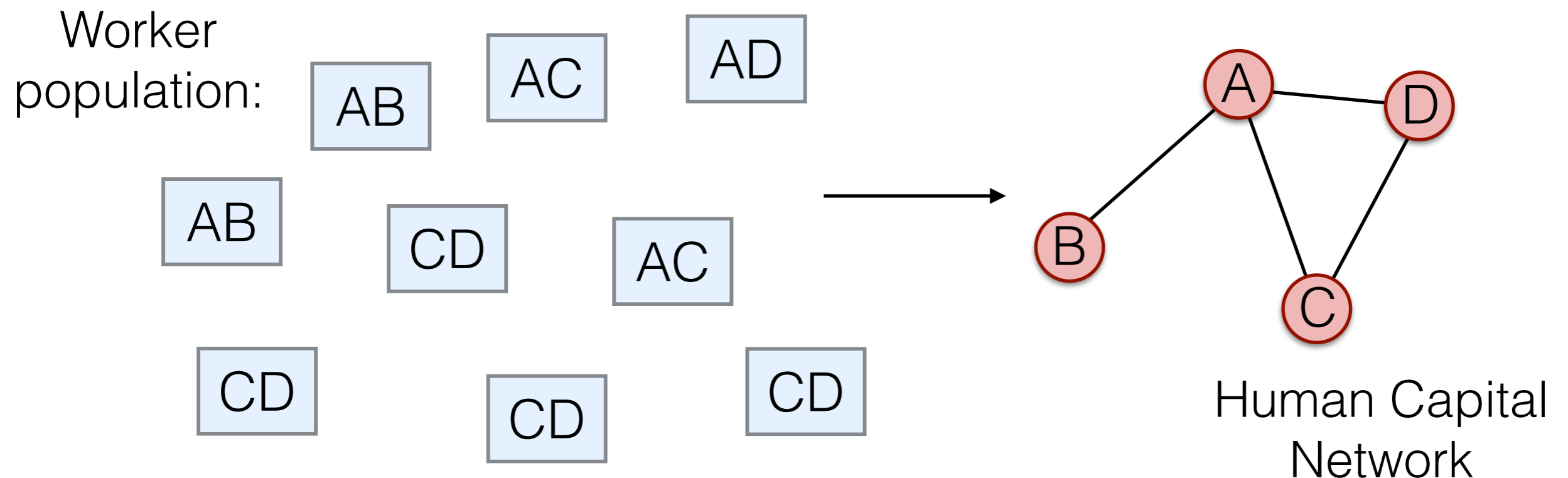
So we need to find different ways to measure and assign  
value to human capital

# Human Capital Networks

Proposal: represent the interactions between worker skills using a network

Nodes = skills

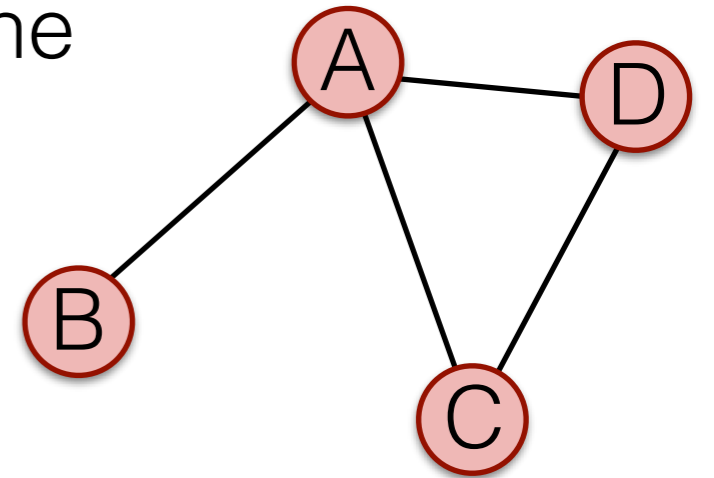
Two nodes are linked if at least one worker has both skills



# Human Capital Networks

We want to weight links to reflect how often the skills co-occur

Some possible weighting schemes:



Counts:  $w_{AB} = n_{AB}$

Jaccard Similarity Index:  $w_{AB} = \frac{A \cap B}{A \cup B} = \frac{n_{AB}}{n_A + n_B - n_{AB}}$

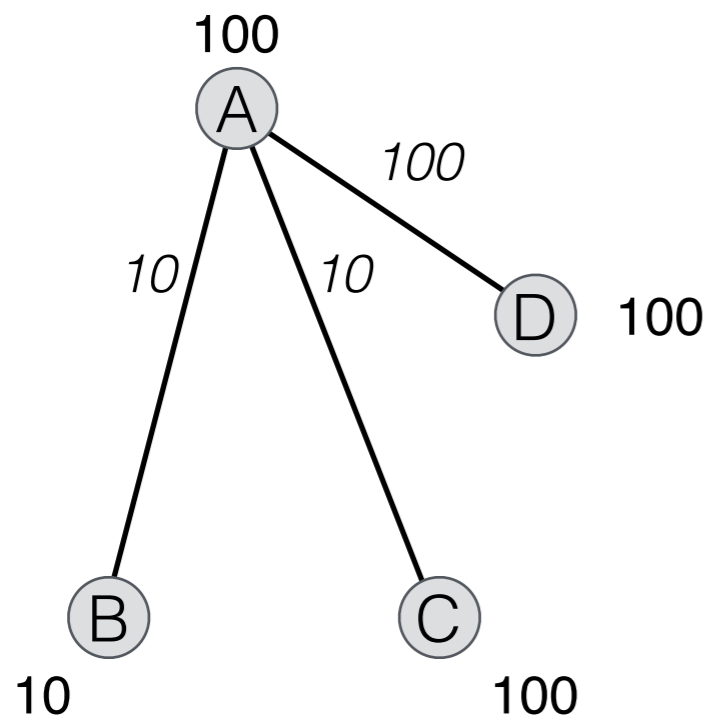
Conditional Probability:  $w_{AB} = \frac{n_{AB}}{n_A}$        $w_{BA} = \frac{n_{AB}}{n_B}$

Modified Conditional Probability:  $w_{BA} = \frac{n_{AB}}{\min(n_A, n_B)}$

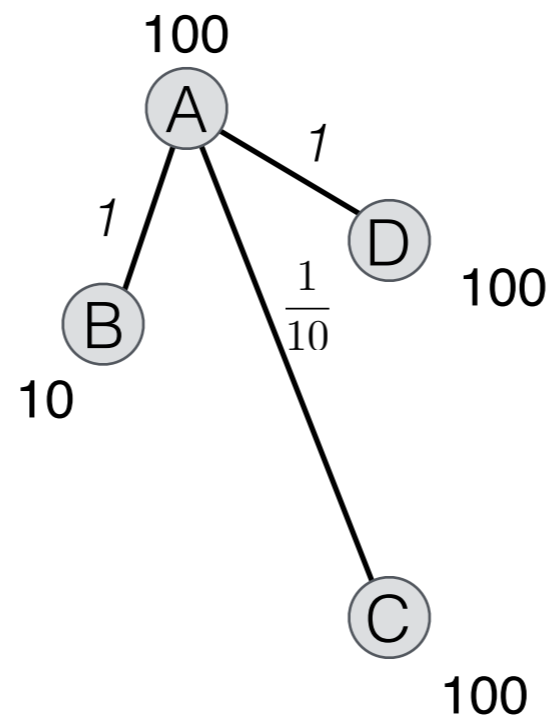
# Human Capital Networks

These different weightings emphasize different aspects of the relationship between skills

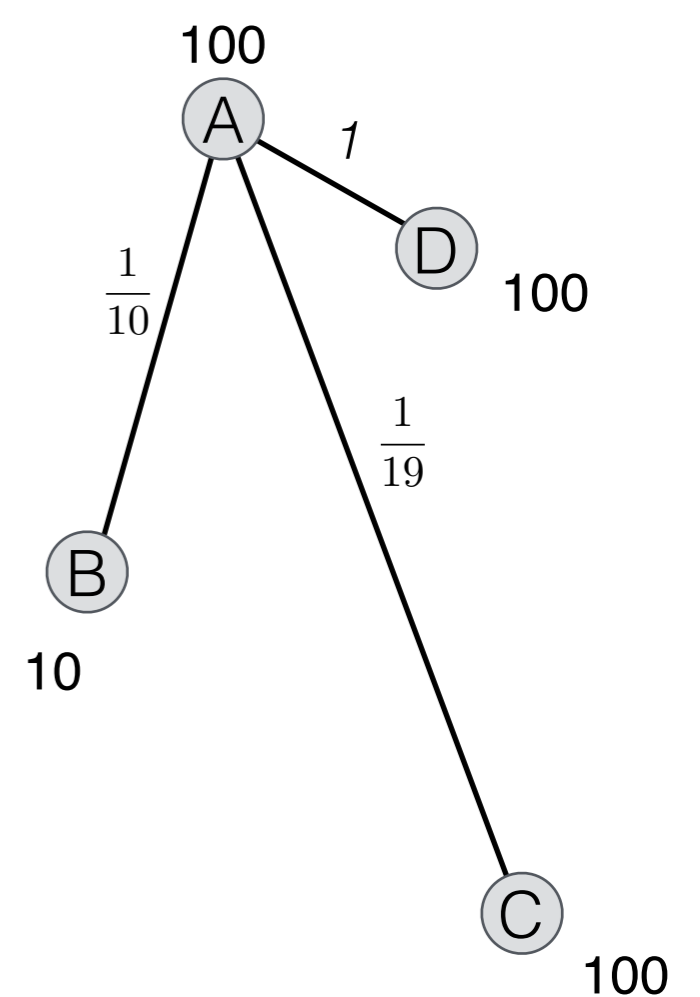
a) frequency weighting



b) modified conditional probability



c) Jaccard Similarity Index







An illustration: a online freelance labor market

In 2014 there were 53 million contract workers, generating \$700 billion

Upwork is the largest online labor market

- 9 million workers
- 4 million clients
- \$1 billion/year

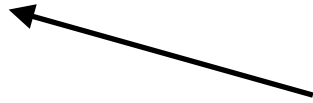
Worker Profiles (skills, biography, test scores, employment history, ratings...)

Job Listings: (skills required, description, wage rate...)

# Why Online Labor Markets?

1) Freelance and contract labor is an increasing fraction of the US labor force

**53 million workers in 2014**  
**Generating \$715 billion**



- Worker flexibility
- Geography-free = larger and more diverse labor pool for employers
- Less costly search process

# Why Online Labor Markets?

2) Employers increasingly search for employees using online tools

- Substitute "low bandwidth" information for "high bandwidth" information
  - Employers choose to use low bandwidth search methods, even when they produce worse matches!
  - Improvements to algorithms would produce better labor market outcomes

# upwork

## Worker profiles:

**Teddy E.**  
Senior software engineer

**Overview**  
Over the last year, I have developed a wide range of solutions:  
Web applications in Lua for both iOS and Android operating systems;  
Desktop solutions in C#, C++  
Cloud server solutions in C#, C++, Java, PHP  
Web solutions in ASP.NET, C#, PHP and Perl/CGI  
I used various kinds of relational databases, such as SQLite, MySQL, PostgreSQL, MSSQL, Sybase and Oracle, and various data representation languages, such as XSL, XSLT and XPath.  
My freelance clients included all kinds of companies and business related and I was employed in various different business settings described in more details in my employment history.  
I was employed as a C++/C# software engineer in a world-leading software publisher in financial risk management, and as a senior technical consultant for a multi-leader in sustainability software.  
My core competences lie in complete end-to-end solution development, management and analysis, and I am looking opportunities to help you build solutions for you or your business.  
My full profile is available on [www.upwork.com](https://www.upwork.com)

**Work History & Feedback**

Developer 2018 - Present Duration: 2 Yrs	"Excellent skills, communication, availability, respect of dates ... in other words, total efficiency. I never worked with somebody so professional."	5.00 ★★★★★
Senior PHP Developer 2016 - 2018 Duration: 2 Yrs	"Great, what can we say? Just top-notch talent, fast responses and really best code I have ever seen. I can't see the future (but would not I - please, please don't retire, we need you to be our best manager, lol)"	5.00 ★★★★★
Senior PHP Dev 2015 - 2016 Duration: 1 Yr	"Expert technical, and top agent"	5.00 ★★★★★
Full-stack engineer 2014 - 2015 Duration: 1 Yr	"Primary work requires, good communication, like you to work with and goals of a good solution/workaround for our problems?"	5.00 ★★★★★
Web development 2013 - 2014 Duration: 1 Yr	"If it was possible to give more than 5 stars, I would do so. A fruitful and seamless experience."	5.00 ★★★★★

There are a wide range of worker types...

## Stephanie V.

Excellent English speaker & writer (Business)  
Manager/Translator

[View Profile](#)
[Send Message](#)
[Add to Favorites](#)

---

### Overview

It's more than a memorandum or an appointment letter. It's a communication, one that carries the message from what I say to the heart and soul. I have had extensive experience in dealing with customers and clients in various fields like retail, customer service, training, quality assurance, account management, and business development. English communication skills is my forte and believe this is my ticket to accomplish tasks asked of me. Writing and speaking are both interests and talents. All the clients give my good work skills, and reliability passed to people who would need detail and timeliness in the work they need done.

---

### Work History & Feedback

Clients needed list of Australian universities and private schools in all states and territories.

Clients needed list of Australian Universities and Private schools in all states and territories.

4.60

★
★
★
★
★

### Tests Taken

Name	Percentage Score
Customer Service Test	100
Excel Spreadsheets Certification	100
English Reading Test (UK - Version)	100
English Listening (Progress) Intermediate Sample Test	100
English Vocabulary Test (A2 B1 - Beginner)	100
Customer Service Skills Test	100
Telephone Etiquette Certification	100
U.S. English Basic Skills Test	100
U.S. English Fluency (Basic Test - Beginner)	100
Quick Response Test for Independent Contractors and Staffing Managers	100

# Job Postings:

**Web designer/WordPress wizard needed! For Membership site and affiliate platform Creation - Simple job for those that know how :-)**

Hours: Less than 1 week • Less than 10 hrs/week • (Fixed) 2 hours, 10 minutes ago

with design • with development • completed

[Post a Job Like This](#)

[Sign up or log in](#)

## Job Description

I need a WEBSITE (WP) either using my old theme (adapt it through a recommended better WP theme plugin) or alternative if recommended. (Must be changed) Nothing is complicated. Simple Membership site (with a M2WP) could access and work through equity time. site will be training videos, training materials and forum products. (I will need to upgrade to site platform)

I will provide all logo, design work, graphics, content content, video content etc. I need it to be put into a WP for Membership platform. (Requires a developer. Can share different areas or training & features will be done. Can also provide example of membership site. When membership site will need to

### Requirements

- Getting started (how) for people that like site and have access to equipment training videos.
- Mobile Site Training (Training courses for upgraded members)
- (WP) Site Training (Lesson with advanced viewing & access)
- Marketing website (to transition to get all hyperlinks, banners, video content)
- Account Details (where members/affiliates can see their sales numbers and earnings & income)
- Content (Upcoming members/Events/Phone calls)
- Support system (to report a question or problem)

My pretty basic website for a membership site. Can discuss details for account/affiliates. Please let me know if you have any questions.

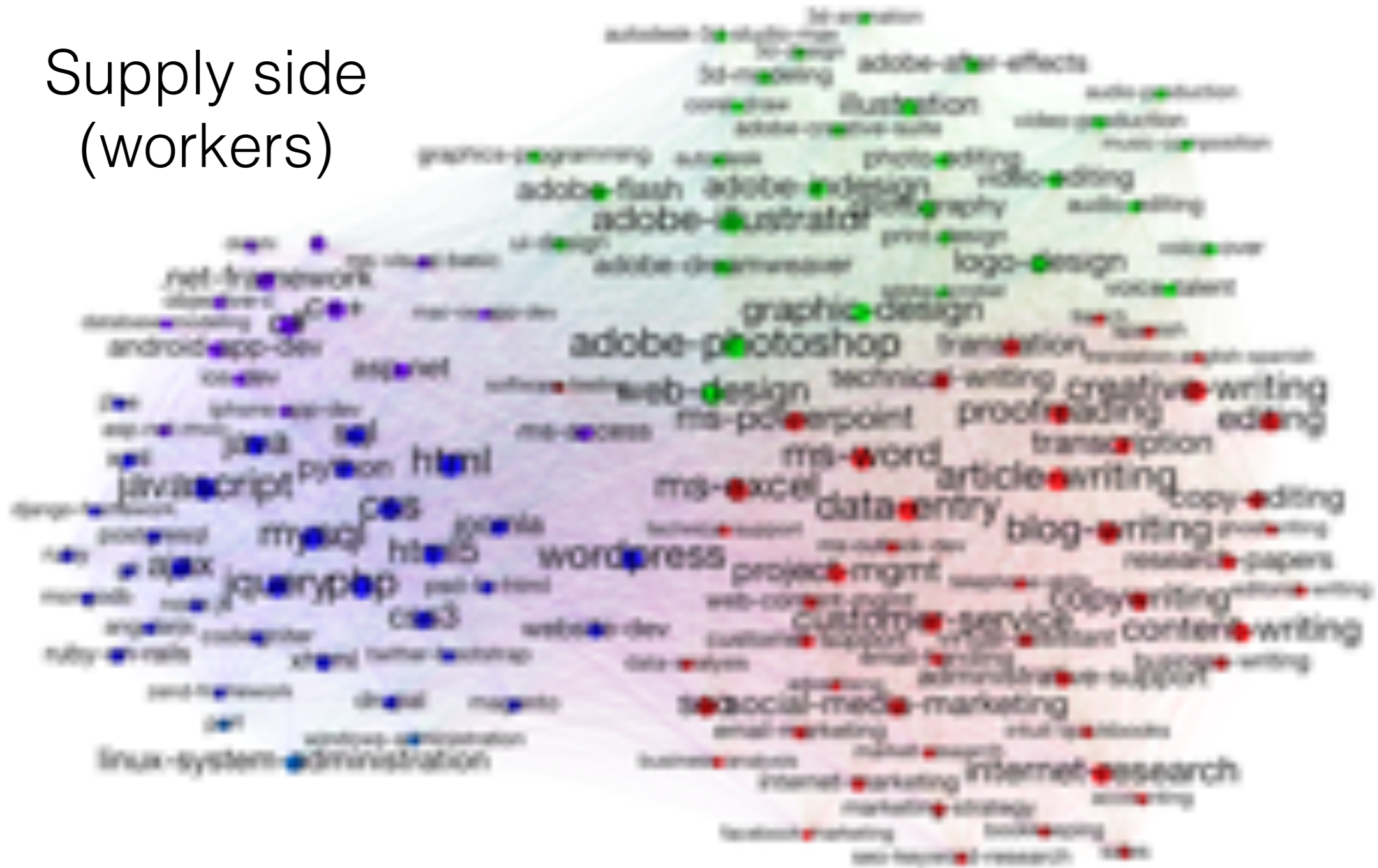
## Job Overview

Job	Details
Posting	As needed: Less than 10 weeks
Duration	Less than 1 week
Time	February 17, 2019, 11:04 PM
Rate	Fixed
Skills	PHP
Category	<a href="#">Website Development</a>
Job ID	<a href="#">104744444</a>
Job type	<a href="#">Freelance</a>



# Human Capital Network

Supply side  
(workers)

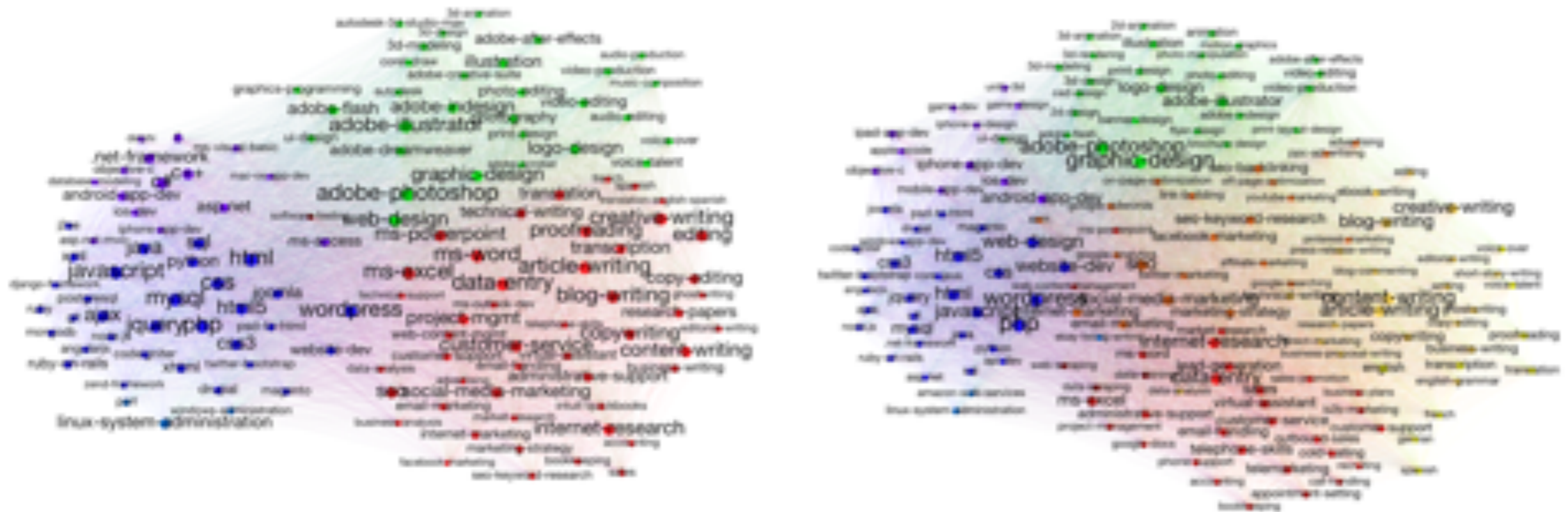






# Communities in the Network

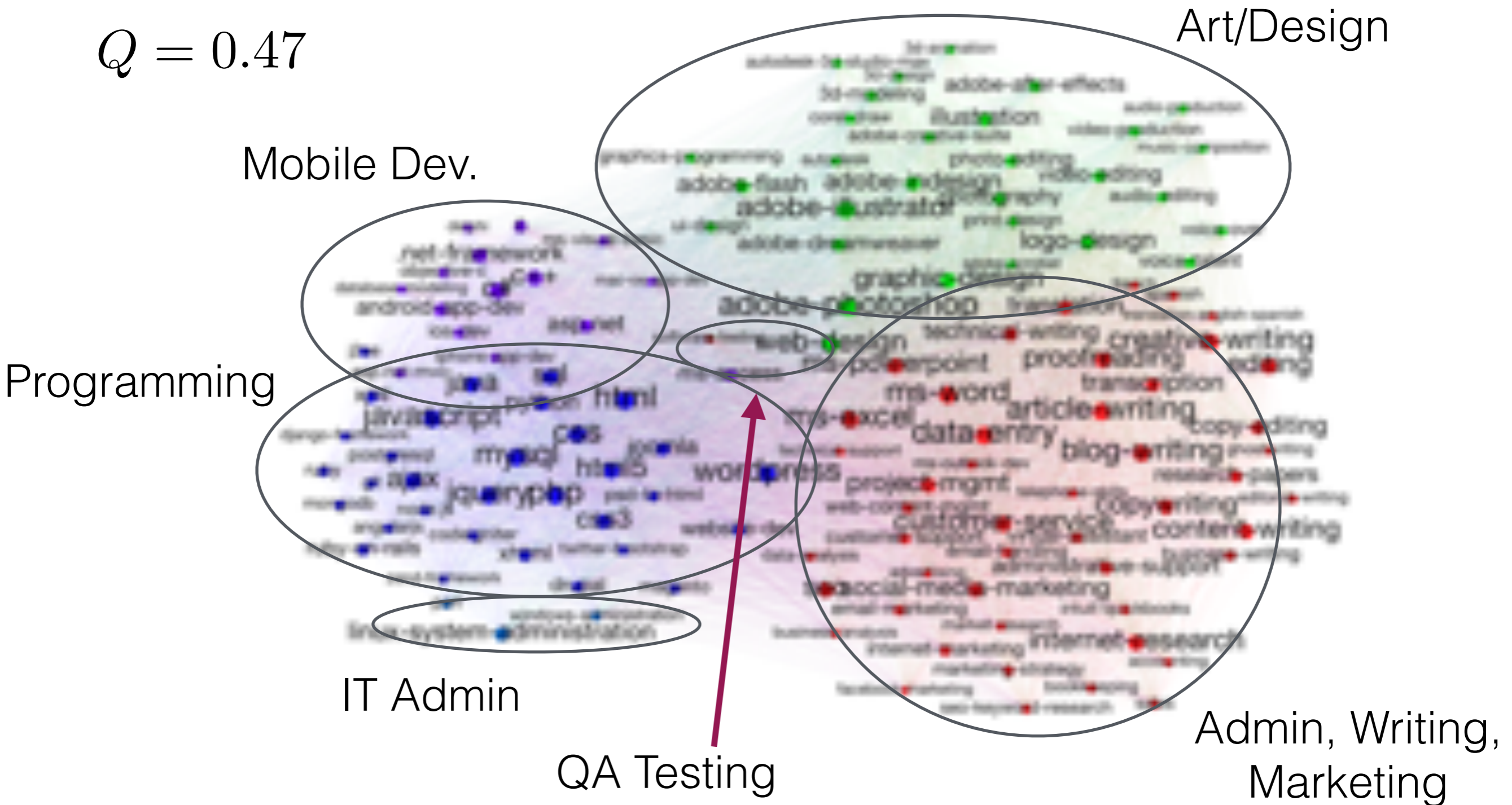
These two networks summarize a huge amount of information about the labor market



For one, by using a community-find algorithm, we can learn something about how the labor market is arranged

# Supply side (workers)

$Q = 0.47$



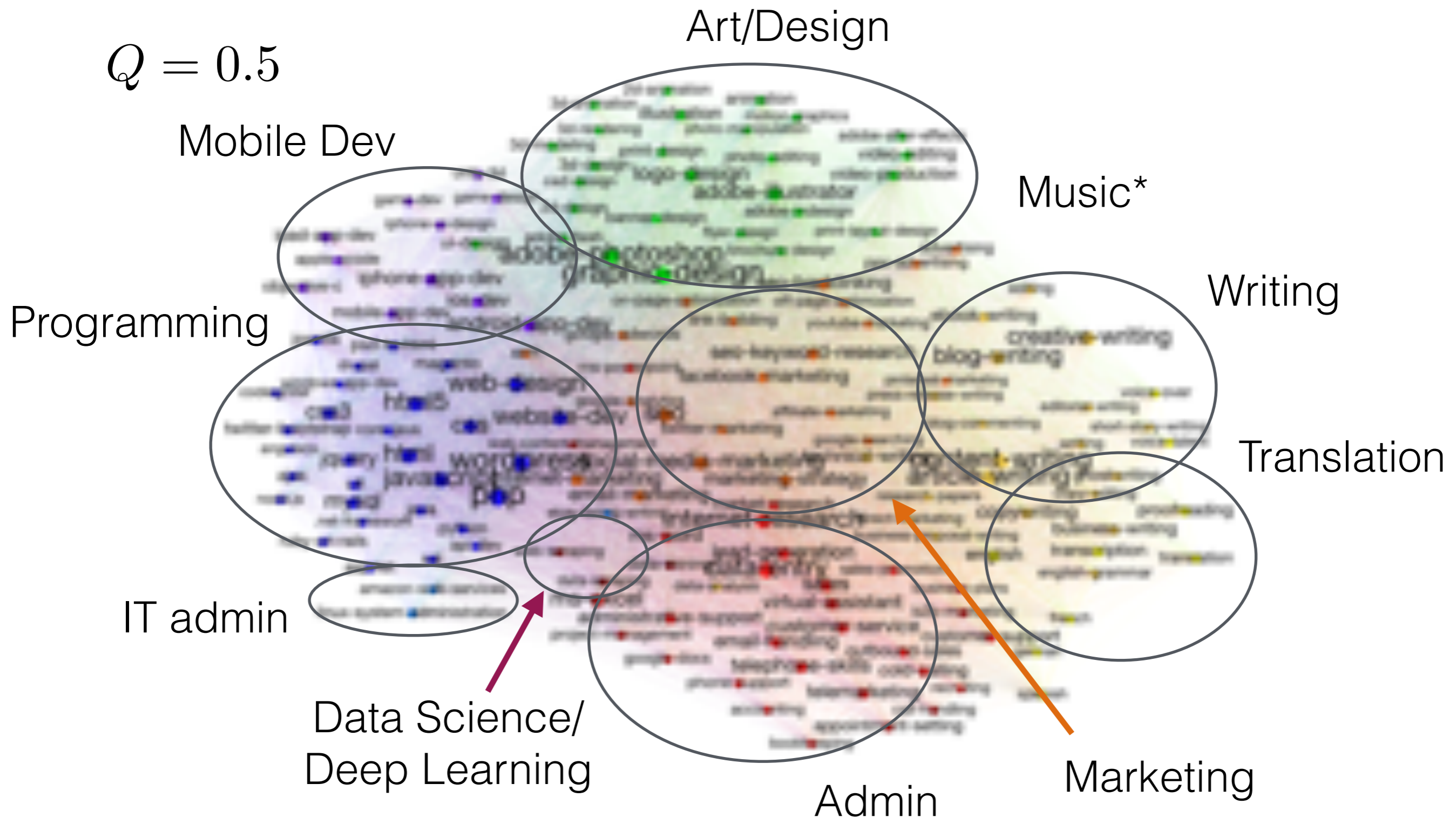
# A Taxonomy of Skills

Admin/Writer/Sales	Artist/Designer	Programmer/Technical			Testing
		General	Mobile/Stats	IT/Network Admin	
microsoft excel	adobe photoshop	php	c#	linux systems admin	software testing
data entry	adobe illustrator	javascript	c++	perl	software qa testing
article writing	web design	html	.net framework	windows admin	manual testing
microsoft word	graphic design	mysql	asp.net	apache admin	functional testing
blog writing	adobe indesign	css	android app dev	network admin	usability testing
creative writing	logo design	wordpress	c	lamp admin	regression testing
internet research	adobe flash	jquery	microsoft access	amazon web services	atlassian jira
customer service	illustration	java	ios dev	unix shell	black box testing
proofreading	adobe dreamweaver	ajax	objective c	computer networking	automated testing
editing	photography	html5	ms visual basic	unix system admin	web testing



# Demand side (employers)

$Q = 0.5$





# A Taxonomy of Skills

Administrative	Writing	Translation	Art/Design	Music/Audio	Marketing
data entry	content writing	english	graphic design	audio editing	seo
internet research	article writing	transcription	adobe photoshop	audio production	social media market
microsoft excel	blog writing	proofreading	adobe illustrator	audio mixing	internet marketing
lead generation	creative writing	translation	logo design	audio post-product	seo keyword research
sales	copywriting	voice over	illustration	music composition	email marketing
telephone skills	technical writing	voice talent	video editing	audio mastering	marketing strategy
virtual assistant	ebook writing	french	UI design	audio engineering	seo backlinking
customer service	business writing	spanish	video production	music producer	facebook marketing
email handling	ghostwriting	german	print design	music arrangement	twitter marketing
telemarketing	english grammar	english to french	animation	sound editing	link-building

Programming/Technical					Testing
General	Mobile Dev	IT/Network Admin	Engineering	Data/Statistics	
php	android app dev	linux system admin	c	data mining	software testing
wordpress	iphone app dev	amazon web services	electrical engineering	data scraping	QA testing
javascript	ios dev	ebay listing writing	electronics	web scraping	web testing
web design	mobile app dev	ebay marketing	matlab	web content mgmt	manual testing
html5	ipad app dev	network admin	pcb design	scripting	functional testing
html	objective c	cpanel	arduino	web crawler	automated testing
css	game dev	email deliverability	microcontroller prog	website wireframing	usability testing
website dev	apple xcode	amazon ec2	circuit design	salesforce apex	database testing
css3	game design	network security	embedded systems	salesforce.com	localization
mysql	iphone UI design	voip software	electrical drawing	salesforce app dev	selenium







# Complex Measures of Human Capital

The position of a workers skills on the two networks characterizes their skill set



Specialist



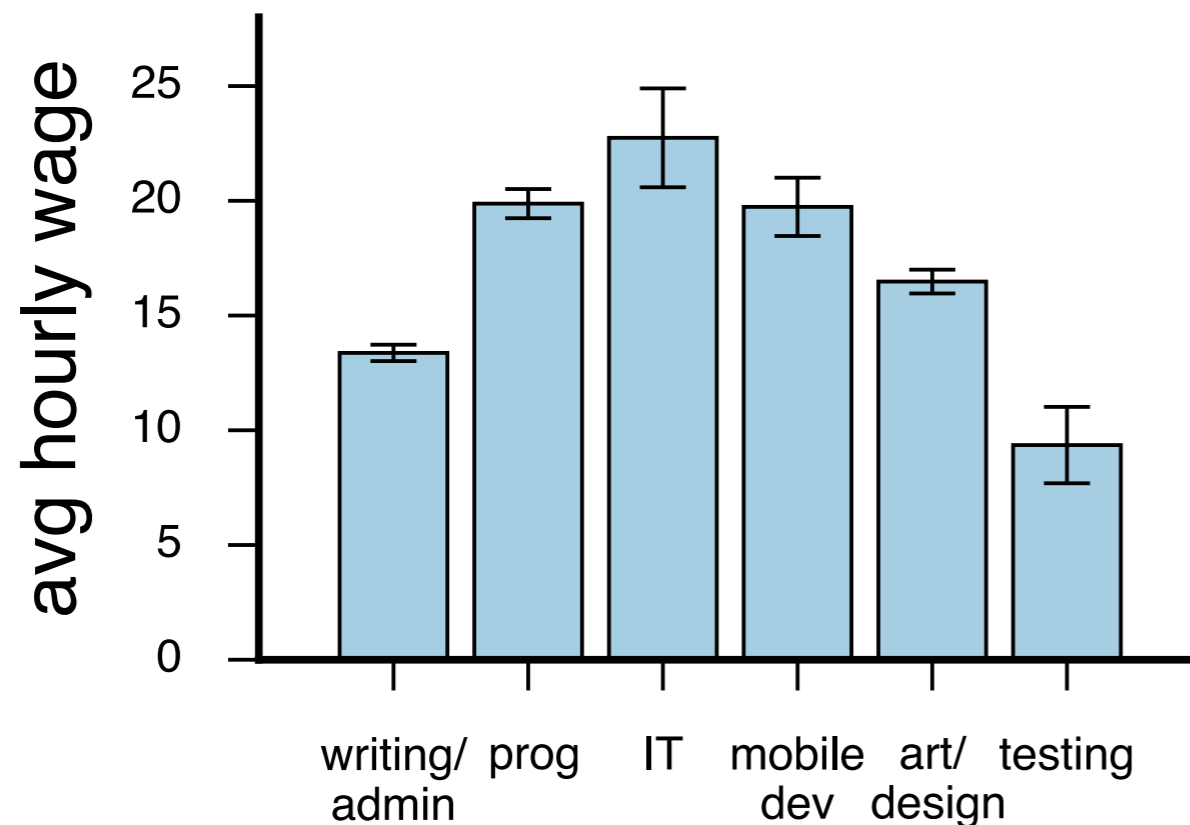
Diverse Skills

Measuring these differences opens up new questions

# Complex Measures of Human Capital

As an illustration...consider workers whose skills fall into a single category

Wages vary dramatically by area of specialization



NB: for now, I control for literally nothing

# Human Capital and Wages

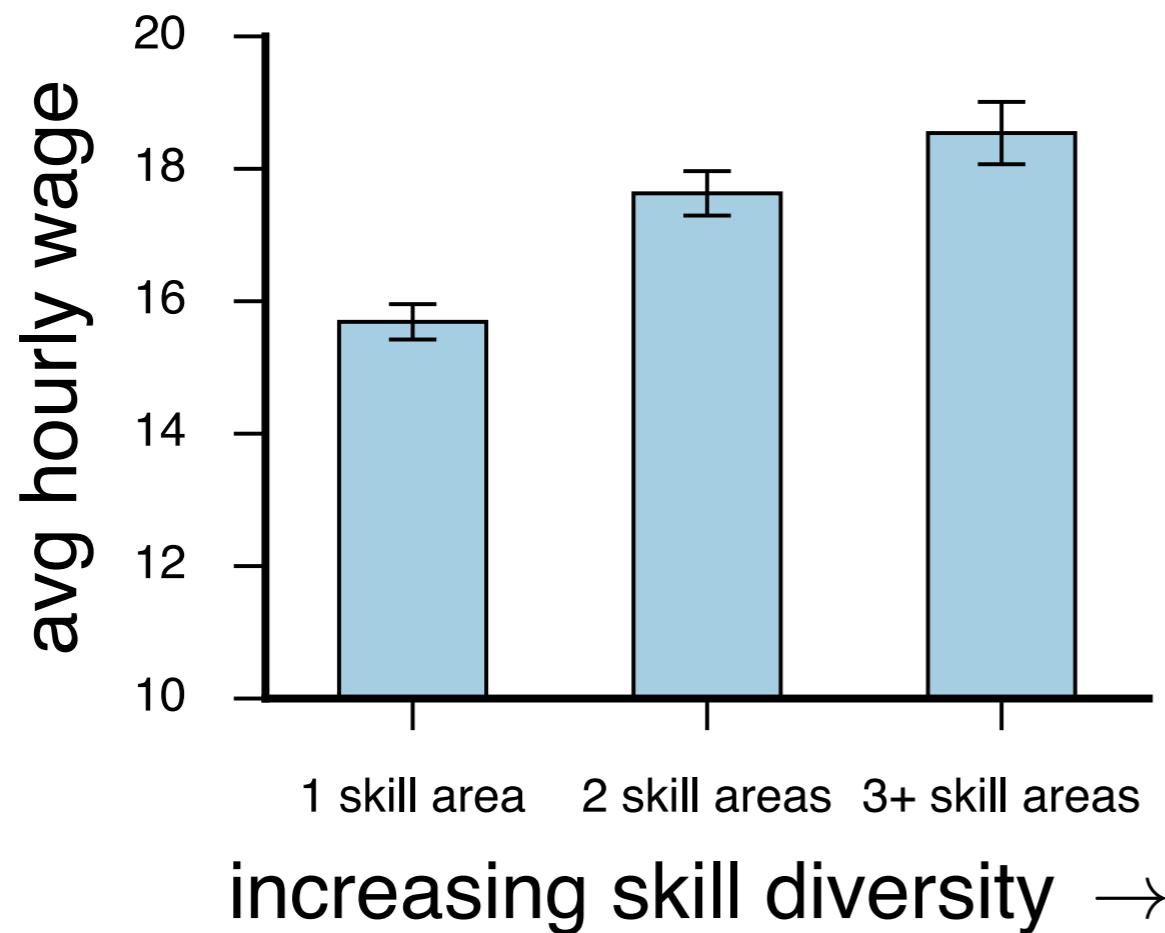
Now compare specialists to those who span multiple categories:





# Complex Measures of Human Capital

Workers with more diverse skills  
tend to earn more

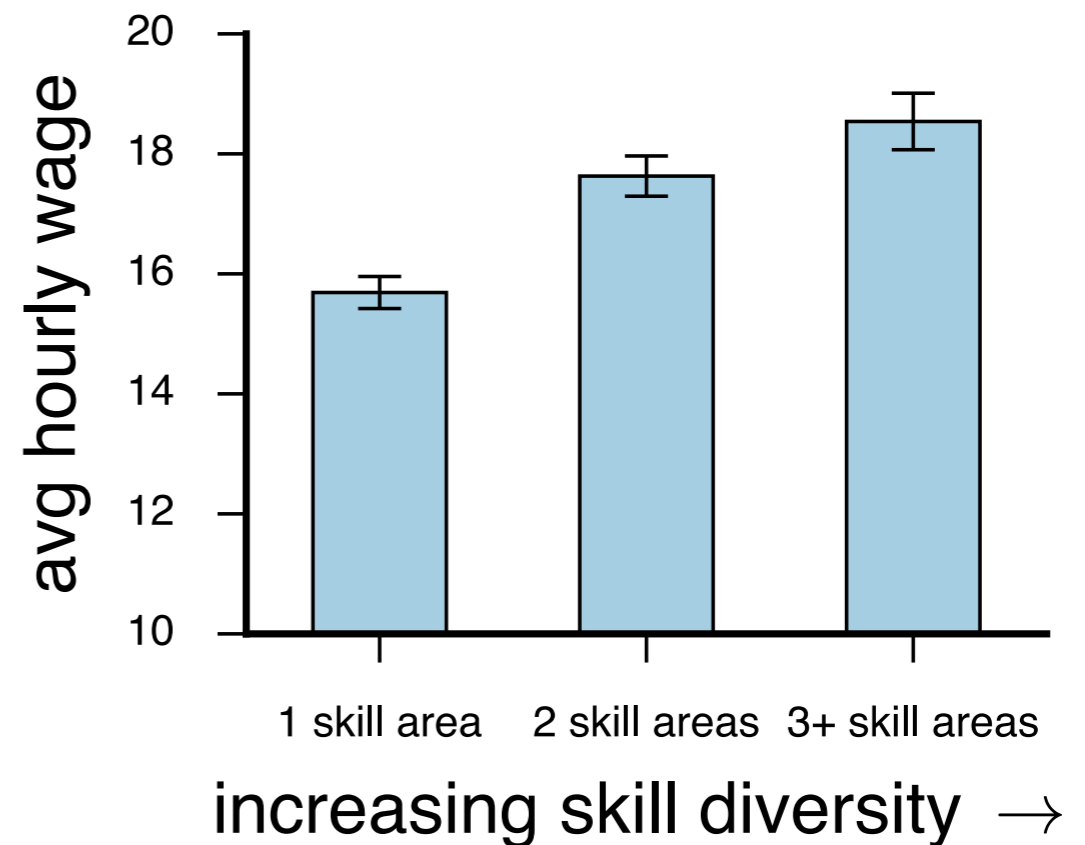


# Complex Measures of Human Capital

But then the question is, *why* do workers with diverse skills earn more?

Two possible advantages:

1. diverse skills =  
larger pool of jobs
2. diverse skills =  
unique gap-filler



# Complex Measures of Human Capital

Difference between the two can be seen in the job network



Skills tightly clustered on the job network are often required in combination



# Complex Measures of Human Capital

Worker  
Network



Job  
Network



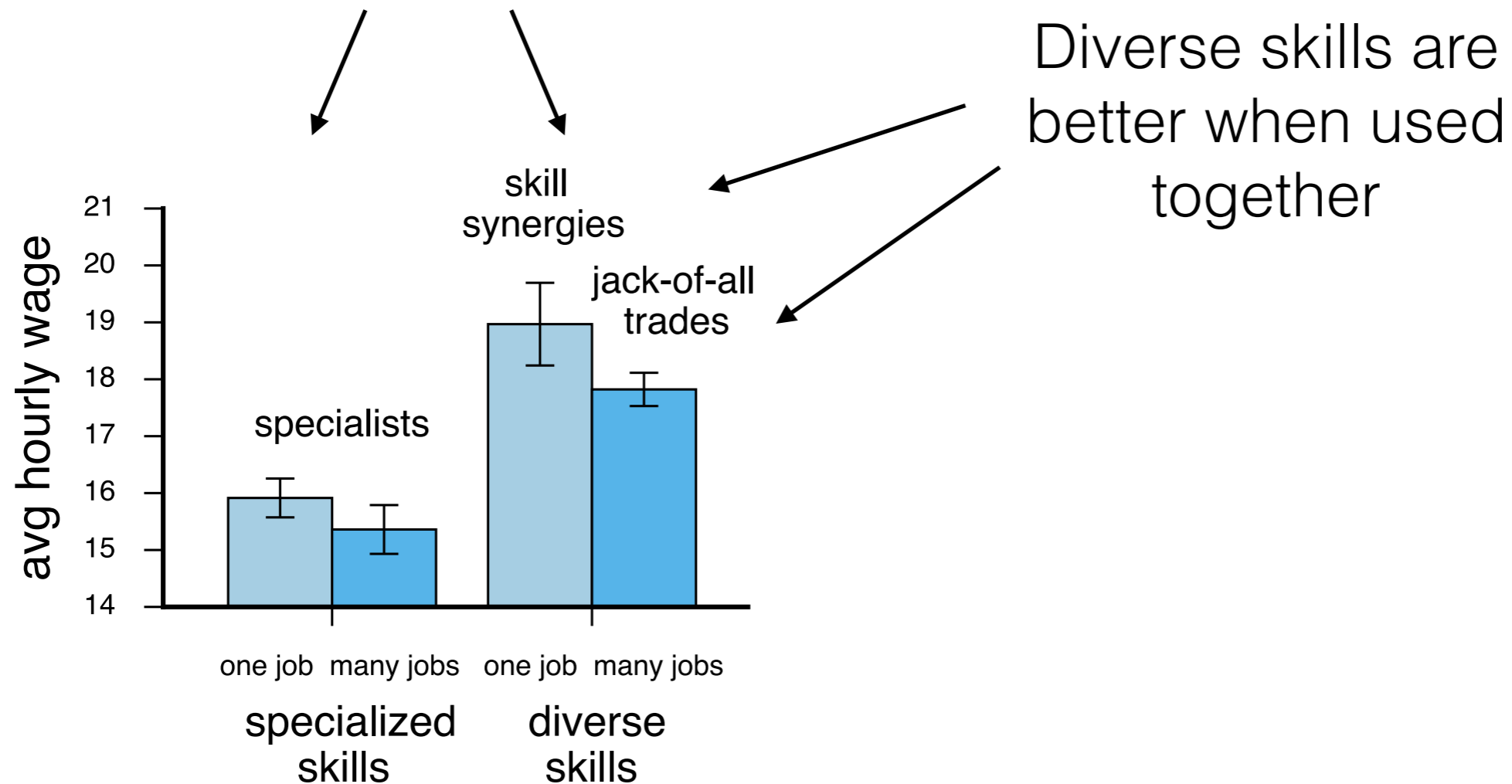
Fit Multiple  
Job Areas



Fit One  
Job Area

# Complex Measures of Human Capital

Skill diversity = higher wages



People who use their diverse skills synergistically tend to earn higher wages

# The Value of Skill Interactions

A totally reasonable question:

Do the network-based measures of skill interactions actually do any better than just looking at a workers skills independently?

# The Value of Skill Interactions

Take an incredibly flexible model specification:

$$\ln(w_{it}) = \beta_0 + \beta_1 S_{it} + \epsilon_{it}$$

← dummies for the 60  
most common skills in  
the labor pool

Compare that to a model including the independent skills *and* network-based measures of human capital

$$\ln(w_{it}) = \beta_0 + \beta_1 S_{it} + \beta_2 X_{it} + \epsilon_{it}$$



# The Value of Skill Interactions

	Model 1	Model 2	Model 3	Model 4
N	18165	8859	18165	18165
Adj $R^2$	0.178	0.190	0.180	0.183
constant	2.6***	2.36***	2.54***	2.51***
program.		0.51***		
IT admin.		0.59***		
mobile dev.		0.47***		
art & design		0.26***		
testing		-0.3***		
number of skill areas			0.05***	
number of job categories				0.05***
html	-0.08***	-0.08**	-0.09***	-0.09***
illustration	0.12***	0.15***	0.12***	0.13***
social media marketing	0.04*	0.12***	0.04	-0.0
mysql	0.08***	0.01	0.07***	0.07***
project management	0.18***	0.24***	0.16***	0.14***
adobe photoshop	-0.13***	-0.17***	-0.14***	-0.15***
microsoft word	-0.15***	-0.11***	-0.15***	-0.16***

The network-based measures are significant even when you control for the skills individually

# The Value of Skill Interactions

## Effect Sizes:

- Programmers earn 51% (~\$5.40) more than Administrative Workers
- QA testers earn 30% (~\$4.00) less
- Workers with an skill in an additional category earn \$0.65 more

# Human Capital and Wages: Skill “Coherence”

So some skill diversity seems to improve outcomes.  
But is there a limit to that?

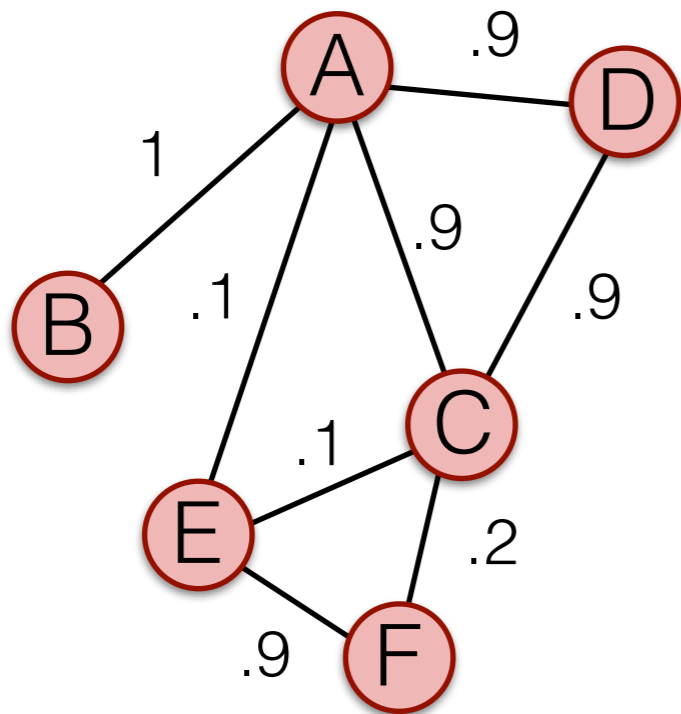
- Sometimes breadth of experience is seen as a positive sign (Renaissance Person)
- Sometimes it is seen as a lack of focus (Dilettante)

So what distinguishes a Renaissance Person from a Dilettante?

Leung 2014: it is not just the *breadth* of experience, but the *coherence* of that experience

# Skill “Coherence”

Measure of skill set coherence: average distance between a workers skills in a particular labor market



weights = Jaccard Similarity Index

$$w_{AB} = \frac{A \cap B}{A \cup B} = \frac{n_{AB}}{n_A + n_B - n_{AB}}$$

Call this *Jl similarity*: how well your skills fit in with those of your peers

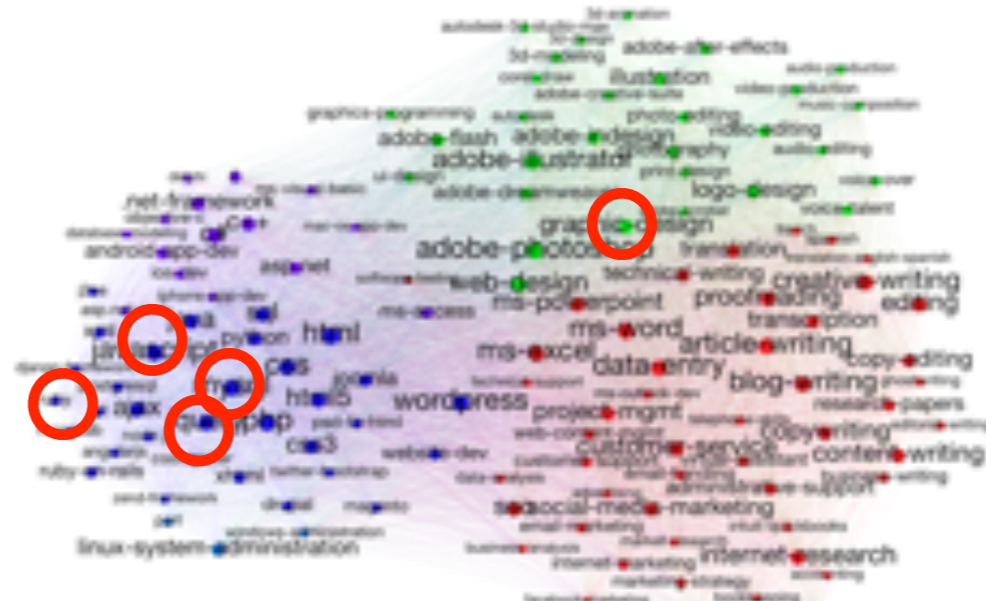
$$\textcircled{A} \textcircled{B} = 1$$

$$\textcircled{E} \textcircled{F} \textcircled{C} = .4$$

# Worker Skill Similarity



High JI Specialization



High JI specialization:  
Diverse, but coherent



Low JI specialization

# Skill “Coherence”

Note: There is a difference between “diversity” and “coherence”

Set Designer + Screen Play Writer + Director = Coherent

Graphic Design + UIX + Mobile Development = Coherent

Underwater Salvage + Creative Writing = Incoherent

# Worker Skill Similarity

$$\ln(w_{it}) = \beta_0 + \beta_1 S_{it} + \beta_2 X_{it} + \epsilon_{it}$$

Workers benefit from adhering to “type”

Workers with many common skills earn lower wages

Dummies for skills in different categories and pairwise interactions

Dependent variable = log wages				
	(1)	(2)	(3)	(4)
	Round 1 data		Round 2 data	
JI similarity	0.699*** (0.0763)	0.466*** (0.0796)	0.479*** (0.0617)	0.276*** (0.0633)
Number of skills	0.0306*** (0.00302)	0.0359*** (0.00378)	0.0375*** (0.00262)	0.0372*** (0.00307)
Number of rare skills	0.0819** (0.0379)	0.0153 (0.0365)	0.0284 (0.0234)	0.00859 (0.0221)
Number of common skills	-0.144*** (0.00874)	-0.125*** (0.00918)	-0.0901*** (0.00688)	-0.0763*** (0.00704)
Number of jobs worked	0.00387*** (0.000287)	0.00419*** (0.000276)	0.00113*** (0.000141)	0.00138*** (0.000134)
Average rating	0.0679*** (0.0122)	0.0719*** (0.0117)	0.136*** (0.0167)	0.146*** (0.0158)
Average test score	0.00119*** (0.000257)	0.00135*** (0.000247)	-0.00693 (0.00518)	0.0101** (0.00494)
Lives in USA	0.0670*** (0.0184)	0.0713*** (0.0182)	0.0895*** (0.0171)	0.0831*** (0.0168)
GDP per capita (logs)	0.0641*** (0.00792)	0.0916*** (0.00771)	0.0812*** (0.00654)	0.110*** (0.00627)
Skill fixed effects	No	Yes	No	Yes
Centroid fixed effects	Yes	Yes	Yes	Yes
Observations	8507	8507	7971	7971
Adjusted $R^2$	0.149	0.222	0.156	0.255



# Summing up

Skill combinations matter!

Employers care about the whole package that an employee brings to the table

The difference between workers may come down to synergies between skills

The benefit of acquiring a skill depends on the skills the employee already has

Online job market markets rely on algorithms to match employees with jobs.

Making those matches requires knowledge of synergies