Who is HCI?
A closer look at Network Structures within Academia

Javonte Tucker
Marquette University
Milwaukee, Wisconsin
javonte.tucker@marquette.edu

Matthew Monge
Marquette University
Milwaukee, Wisconsin
matthew.monge@marquette.edu

Devansh Saxena
Marquette University
Milwaukee, Wisconsin
devansh.saxena@marquette.edu

ABSTRACT

Despite the abundance of on-going research within the Human Computer Interaction (HCI) community, relatively little exploration and research has been conducted towards understanding this research community itself and the reasons for its dramatic growth as a multi-disciplinary domain. In this paper, we explore the network structures that exist between organizations and researchers that contribute to Computer Human Interaction (CHI); the premier venue for HCI research. We specifically analyze Proceedings of CHI 2019 to reveal the epicenters of HCI research. Having uncovered the network structures, we used topic modeling to analyze the abstracts of papers published by top schools to add context to the type of HCI research being undertaken. We found that University of Washington is the epicenter for socially-driven HCI research whereas, Carnegie Mellon University is the epicenter for technically-driven HCI research. Moreover, prominent authors who hold more social capital and act as information brokers help foster new ideas and create new knowledge in this research domain.

CCS CONCEPTS

• **Social network analysis**; • **Topic modeling**; • **CHI 2019**; • **Human-computer interaction**;

KEYWORDS

social network analysis, topic modeling, CHI 2019, human-computer interaction

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1 INTRODUCTION

Human-computer interaction (HCI) is a research domain that traditionally seeks to understand how people use and engage with technology, that is, the interface between computers and people [28]. However, over the past two decades HCI has growth into a multi-disciplinary domain that now sits at the intersection of computer science, engineering, behavioral sciences, media studies, sociology, and several other academic disciplines. Introducing a new technology in the society is an ecological change that not only impacts the relationship that people have with technology but their relationship with other people and their interactions in society [27]. As computer science pushes its boundaries and technological systems begin to permeate into the social sphere, it becomes important for academics to be able to view and understand these changing relationships from a broader perspective than just narrow a technical view. This means looking beyond the engineering bubble and address the broader implications as perceived by academics in other disciplines. To develop pragmatic systems that solve problems in a transparent, accountable and ethical manner; HCI researchers have continued to embrace other academic disciplines that have a better understand of human behavior and the society. These are some of the reasons why the HCI community has continued to grow as a multi-disciplinary area of research.

We wanted to gain a better understanding of this ever-growing HCI community through the lens of network science to see what the social networks within the HCI community look like. For this research study, we wanted to analyze the power structures in the HCI community and understand which areas of HCI research they focus on. Moreover, we wanted to analyze the egocentric networks of prominent HCI researchers to understand how they contribute to the HCI community. In this paper we seek to answer the following research questions –

RQ1: *Who are the prominent HCI researchers and how do they contribute to HCI research?*
RQ2: *Which are the central organizations in HCI community and who do they collaborate with?*
RQ3: *What are the dominant themes/areas that HCI researchers are working on?*

2 RELATED WORK

Understanding social networks in academia is an on-going area of research in itself with implications that impact the relationships between researchers as well as researchers' relationship with their respective organizations. Angervall et al. [2] investigated social networks in two areas of Education Sciences with integrated and collaborative networks. They found that this structure of research collaboration created a well-defined career path for its members who jointly produced and accumulated social capital as a collective group. Gonzalez et al. [9] investigated social networks in academia and provided useful insights that are specific to network structures in academia. They state that dense networks in academia negatively affect productivity and hinder the creation of new knowledge. Moreover, division of labor, in the sense of interdisciplinary research increase productivity of researchers and lead to the creation of new ideas. Barthauer et al. [4] investigated developmental egocentric networks and showed that they are beneficial for women researchers' career success and advancement. These networks provide access to social capital which is less attainable otherwise. Miramontes et al. [25] examined the impact of external collaborations on engineering research and found that structural holes and lower density had a positive effect on research output. This result confirmed that some networks with network closure and brokerage can benefit the performance of the members of the network. Badar et al. [3] explored the role of research performance and degree centrality in co-authorship networks and found that high degree centrality is more so a function of the research performance of the researcher, that is, researchers who publish more in terms of impact factor, attract more co-authors.

For this research study, we wanted to build upon the relevant research into social networks in academia and see if we find evidence of some of the claims made by the research studies discussed above in regards to the HCI community.

3 DATA AND METHODS

We downloaded the program book for CHI 2019 titled, "Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems" from the ACM Digital Library. The table of contents of the program book listed all the 702 papers being presented at the conference along with the author names and affiliated organizations. Next, we used the *R* programming language to import and manipulate this data to create the final data frame with four columns - *Paper_ID*, *Paper_Title*, *AuthorName*, and *OrgName*. *Paper_ID* acted as the unique identifier which associated the affiliated authors and organizations to each unique paper. Finally, we also wanted to gather the *Abstracts* for all the papers in our corpus. We used google scholar to manually search for papers and save the abstracts locally. For analysis, we organized the data in the following three components –

(1) Author-by-Author adjacency matrix: This adjacency matrix uncovers the relationships between authors and co-authorship networks.
(2) Institution-by-Institution adjacency matrix - This adjacency matrix uncovers the institution level social networks and depicts which organizations are collaborating on research as well as the strength of those relationships.
(3) Abstracts used for topic modeling – Network analysis allows us to see the relationship between organizations and authors but it does not give us any information about the context under which these relationships exist or occur. Themes generated by topic modeling allow us to learn about the research of specific organizations and authors. Moreover, this new information can be used in larger networks to help refine those network models.

The data set underwent very little cleaning on our end. All the data required to prepare this data set, that is, paper titles, abstracts, author names and affiliated organizations, was fully available. Therefore, we did not encounter instances of missing or incomplete data. Some authors specified two organizations as their organization of affiliation. For instance, Alexandra Chouldechova listed both Carnegie Mellon University and Microsoft Research. In this scenario, we only considered the first listed organization by authors to ensure a one-one relationship between authors and organizations. This was necessary to ensure that no organization's contribution to HCI research papers was overly inflated because some researchers have industry collaborations that they affix to their names.

4 RESULTS

In this section, we present our key findings from the data analysis. We begin by first discussing the descriptive characteristics of our data set. Next, we organize and present the results by our three research questions.

General Characteristics of the Data Set

We begin this research study with a general exploration of the data set and network structures. Table 1 depicts the frequency of publications by organizations and authors. University of Washington was affiliated with most number of papers at CHI 2019 (n=60) followed by Carnegie Mellon University (n=38). Referring to the network graph in Figure 1, we can see University of Washington and Carnegie Mellon University appear as the two big epicenters. Figure 1 also illustrates that University of Washington's biggest collaborators are University of Michigan and Microsoft Research.

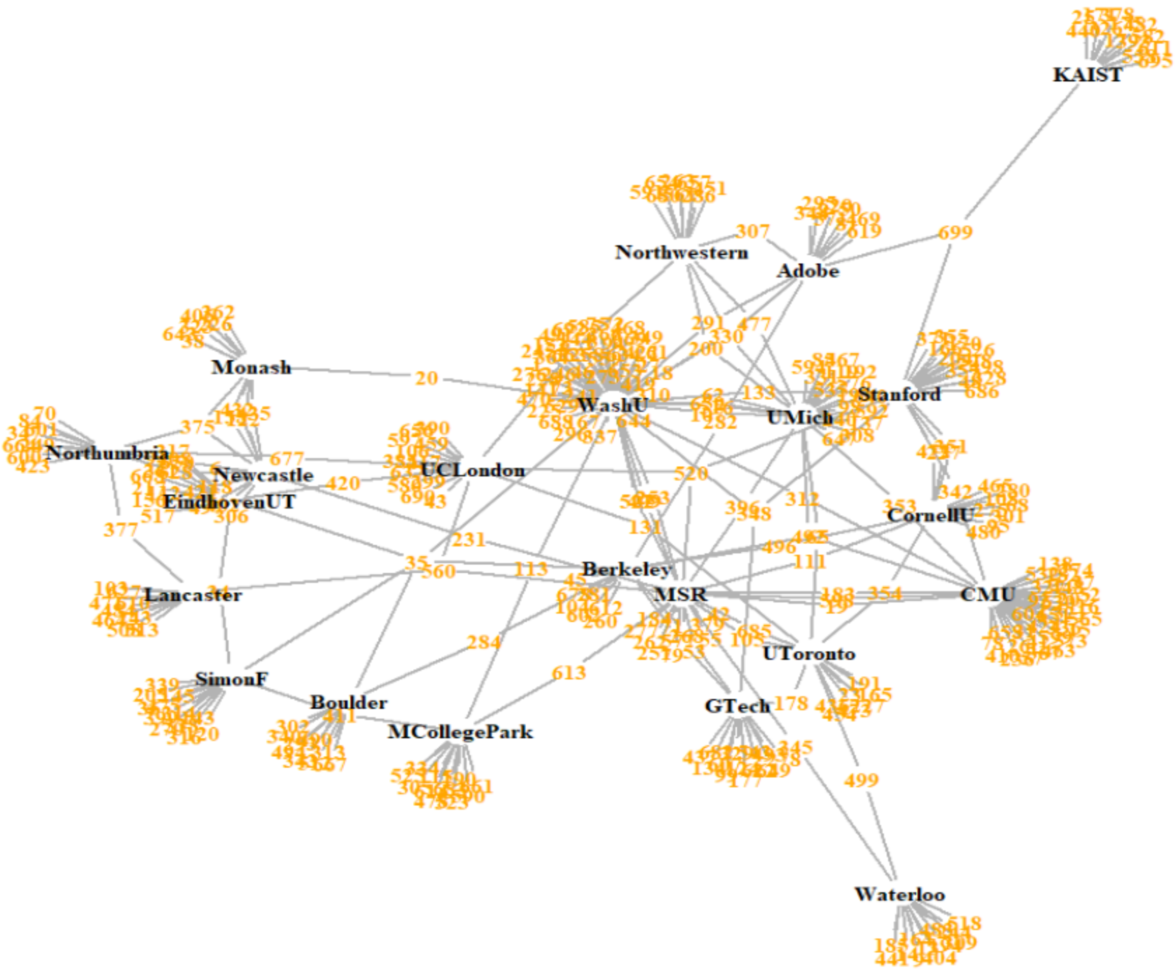

Figure 1: Network structure for organization with more than 10 publication in CHI 2019

School	*Count*	**Author**	*Count*
University of Washington	60	Steve Benford	8
Carnegie Mellon University	38	Daniel Vogel	7
Microsoft Research	27	Chun Yu	6
University of Michigan	27	John Vines	6
Stanford University	20	Kasper Hornbaek	6
University College London	18	Xiaojun Bi	6
Georgia Institute of Technology	17	Alexis Hiniker	5
Simon Fraser University	15	Antonio Kruger	5
Cornell University	14	Carl Gutwin	5
KAIST	14	Christian Holz	5
Newcastle University	14	Lining Yao	5
University of California Berkeley	14	Margot Brereton	5
University of Maryland College Park	14	Niels Henze	5
University of Toronto	14	Yuanchun Shi	5
University of Waterloo	14		

Table 1: Number of publications at CHI 2019 by schools and authors

Moreover, we see that Carnegie Mellon's biggest collaborators are Microsoft Research, Stanford University, and University of Michigan. Table 1 also depicts the top authors that were affiliated with the most number of papers with Steve Benford (n=8), Daniel Vogel (n=7), and Chun Yu (n=6) with the most papers. Next, we created author-by-author and organization-by-organization adjacency matrices to better understand who these authors and organizations are collaborating with and the strength of those collaborations.

Which researchers are well-connected? (RQ1)

We created an author-by-author adjacency matrix to understand how many unique researchers the top authors (as depicted in Table 1) were collaborating with as well as figure out who were their top collaborators. Figure 2 illustrates the top researchers with the most number of unique collaborations. We noticed that this list of top researchers was different

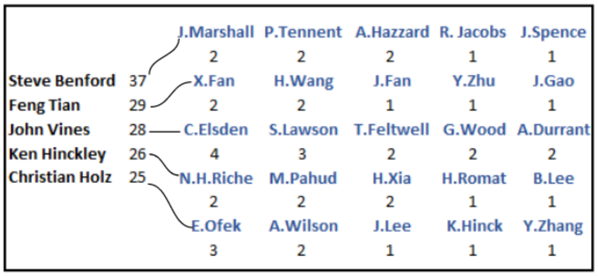

Figure 2: Author-by-Author adjacency matrix

from the list of researchers affiliated with the most papers (see Table 1). Steve Benford was associated with 8 papers and has 37 unique collaborations. However, Daniel Vogel was associated with 7 papers but only had 16 unique collaborations. This finding hinted at the fact that Daniel Vogel's egocentric network might be more densely connected than Steve Benford's egocentric network because the 16 researchers in Daniel Vogel's network would have likely collaborated to publish the 7 papers. Figure 3 illustrates Steve Benford's egocentric network and we see that only 3 out of the 37 collaborators have worked on more than one paper. This implies that Steve Benford worked with 5 unique groups for the 8 papers he published. Figure 4 depicts Daniel Vogel's egocentric networks and we see that 4 out of the 16 collaborators have worked on more than one papers and Daniel Vogel worked with 3 unique groups to publish the 7 papers. In case of Daniel Vogel's network, only two more edges would make the network full-connected, however, Steve Benford's network would require 5 more edges.

Figure 6 depicts all the researchers at CHI 2019 who were affiliated with 5 or more publications. We will refer to this group as the *"First-tier"* of top researchers. This network graph focuses on first-tier researchers' relationship with other first-tier researchers while ignoring smaller collaborations. For instance, as previously depicted, Steve Benford worked with 37 unique researchers. However, this figure depicts that while Steve Benford might be collaborating with other researchers, he is not working with any other first-tier researchers. As depicted by the disconnected network, this holds true for other first-tier researchers as well.

Figure 7 depicts all the researchers who had at least 3 publications but less than 5 publications. We will refer to this group as the *"Second-tier"* of top researchers. This network graph is significantly more connected than the network graph for first-tier researchers.

Which institutions collaborate together (RQ2)?

Figure 1 illustrates the network graph for universities and organizations that were affiliated with 10 or more publications at CHI 2019. We see University of Washington (labeled

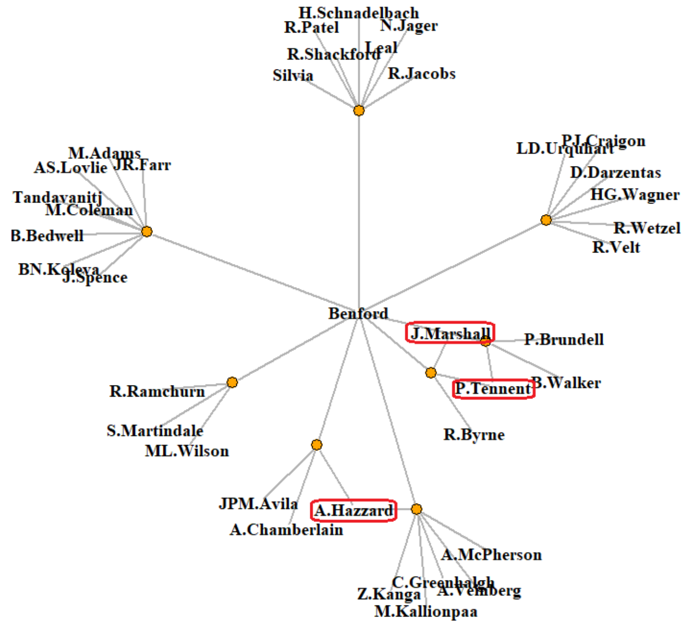

Figure 3: Steve Benford's egocentric network

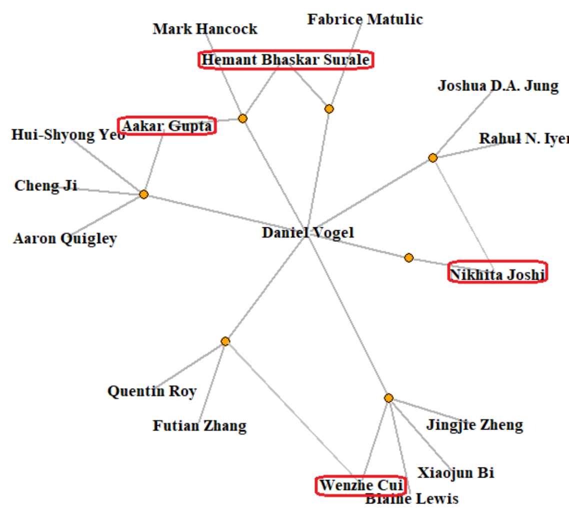

Figure 4: Daniel Vogel's egocentric network

"WashU") and Carnegie Mellon University (labeled "CMU") emerge as the two big epicenters for HCI research within the United States. We also see other pertinent clusters emerge in this graph. For instance, in the top left corner, we see universities in western Europe (United Kingdom and the Netherlands) working together closely. Northumbria University, Newcastle University, Eindhoven University of Technology, and University College London have collaborated on several papers with their closest non-UK collaborator being

Monash University in Australia. For the purpose of this research study, we will focus on the top two HCI epicenters in the United States, that is, University of Washington and Carnegie Mellon and focus on their collaborations.

Figure 5 illustrates the institution-by-institution adjacency matrix for the top HCI institutions. We see that University of Washington had 52 unique collaborations with other institutions at CHI 2019 with the top collaborators being University of Michigan (n=6), Microsoft Research (n=6), and Northwestern University (n=2). Carnegie Mellon University had 33 unique collaborations with Microsoft Research (n=4), University of Michigan (n=3), and Stanford University (n=2) being the top collaborators. We also created egocentric networks for both University of Washington and Carnegie Mellon University. We noticed that University of Washington collaborates with many of the same institutions as University of Michigan (for e.g., Northwestern University, University of Colorado Boulder, University of Maryland College Park). We also noticed that Carnegie Mellon University collaborates with the same schools (Cornell University, University of California Berkeley, Microsoft Research) as Stanford University even though they only shared two publications amongst between them at CHI 2019. Network science helped us unveil these smaller social networks between schools, however, it does not provide us with any information in regard to the reasons for these collaborations. Therefore, we turned towards topic modeling to examine the specific HCI research areas that these schools are working on. To accomplish this, we first gathered the abstracts for all the papers published at CHI 2019.

Research Areas across the HCI community (RQ3)

We wanted to assess the dominant HCI research themes that appeared at CHI 2019. To accomplish this, we gathered the abstracts of all the research papers in CHI 2019 and conducted topic modeling on this corpus of abstracts. The full topic models are available in the appendix of this paper. We compiled the followings topics – "User engagement", "Virtual Reality", "Security and Privacy", "Interaction Design", "Quantitative Study", "User interaction with VR", "User study", "Ethnography", "Design Checklist", and "Design tech for human services". We could intuitively see that these topics aligned with two different schools of thought, that is, "socially-driven" research and "technically-driven" research. To gain a better understanding of the dominant HCI research themes, we went back to Figure 1 to find the dominant collaborations so we could individually topic model those groups.

HCI themes at University of Washington

We ran topic modeling on the abstracts of papers published by University of Washington and its top collaborators to help discover the context of relationships between the university and its collaborators. The institution-by-institution adjacency matrix tells us that the University of Washington collaborated with 52 distinct organizations. The University of Michigan being one of the top collaborators with a total of 6 papers worked on with University of Washington. After running topic modeling on these abstract, we discovered majority of the papers written between University of Washington and University of Michigan involved themes around social issues and health. A short list of topics we compiled include: “Technology for human services”, “Understand needs of users” and “Technology for human services”. We were able to generate these topics by running LDA on the abstracts. The most recurring words were: “interviewed”, “design”, “research”, “social”, and “participate”. These words generally have a common theme of user engagement, which is an integral component to the type of research University of Washington and University of Michigan conducted. We can now infer that the type of research conducted included people’s feedback on the technologies that were being developed. The diction in these collaborated papers are noticeably distinguishable between papers collaborated on between Stanford University and Carnegie Mellon University, which we discuss below. The use of topic modeling is useful in the sense that we did not have to read every single paper to understand the conversation between these organizations. Additionally, it provides a more qualitative component to the type of research that was conducted between the organizations as opposed to a quantitative one.

HCI themes at Carnegie Mellon University

Aside from running topic modeling on solely the abstracts from University of Washington and its collaborators, we decided to also follow the same procedure on the abstracts of papers from Carnegie Mellon University and its top collaborators. We noticed a distinct difference in themes found from these universities. While the former group of universities focused on social issues and health, the latter group focused on more technical and design-oriented topics. A short list of topics we compiled include: “Engineering design process”, “Wearable devices”, and “Pedestrian guidance system”. These topics were also generated from running LDA on the abstracts. The most recurring words were: “design”, “interact”, “investigate”, “technique”, and “device”. These words typically have a common theme of technical interactivity and design, which is a significant component to the type of research conducted by Stanford University and Carnegie Mellon University. There were many instances of innovative technologies that were being developed with new techniques which served new purposes. We can now infer that the type of research conducted included hands-on development of devices that were used to improve human computer interaction. While these universities collaborated and conducted different kinds of research, all of these topics still thematically linked to technical interactivity for improving human computer interaction.

HCI themes at KAIST

Figure 1 depicts the Korea Advanced Institute of Science and Technology (KAIST) at the periphery of the HCI community with just one collaboration with Adobe Research and Stanford University. We verified their collaborations with the CHI 2019 program book to ensure that an error did not occur in our analysis. KAIST is a strong HCI contributor with 14 publications at CHI 2019. Therefore, we decided to analyze abstracts of papers published by KAIST using topic modeling to determine the dominant themes. A short list of topics that we compiled include: "virtual reality", "social robots", "dexterity", "tactile perception", "visual guidance", and "voice navigation". Through these themes, we surmise that HCI research at KAIST focuses on user interaction design. More specifically, the papers at CHI 2019 focused on human-robot interaction and virtual reality.

HCI themes at University of Waterloo

Figure 1 depicts University of Waterloo with just two collaborations with the broader network. Therefore, we decided to analyze the abstracts of papers published by researchers at University of Waterloo to better understand their focus of HCI research. A short list of topics that we compiled include: "gesture control", "virtual reality", "designable markers", "touch input", "social robots", "controllability". We surmise that researchers at the University of Waterloo are working on user interaction design and virtual reality.

HCI themes in western Europe

Figure 1 depicts a strong collaborative network between the universities in western Europe, namely, Newcastle University, Northumbria University, Eindhoven University of Technology, and University College London. We analyzed the abstracts of this group to uncover the dominant HCI themes. A short list of topics that we compiled include: "social justice", "performing arts", "ethnography", "artisans", "maker movement", "critical theory", "citizen science", "perceptions". We continually circled back to the abstracts to search for specific words from the abstracts (for e.g., "maker") to understand where the specific words in our topic models were originating from and added context to the topic. From these topics we surmise that these schools engage in more socially-driven

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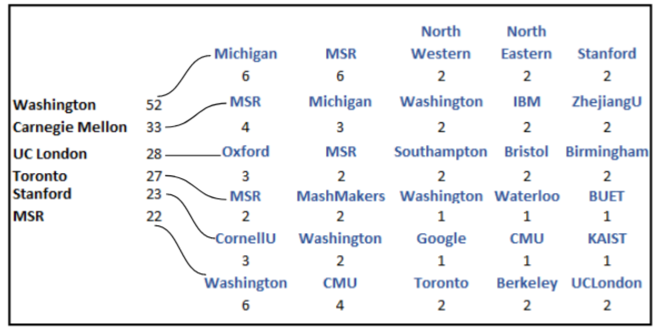

Figure 5: Institution-by-Institution adjacency matrix

HCI research to understand how technology affects peoples' lives.

5 DISCUSSION

Is too much social capital a bad thing (RQ1)?

Our results depict Steve Benford and Daniel Vogel as some of the most prominent HCI researchers with each researcher publishing at least 7 papers in CHI 2019. However, Steve Benford collaborated with 37 unique researchers whereas, Daniel Vogel collaborated with only 16 unique researchers. Traditionally in social networks, less-dense networks with information brokers is considered detrimental for information flow in the network because a couple of nodes have much higher social capital and control this flow of information [5]. However, research on social networks in academia shows that dense networks negatively impact the creation of new knowledge within a social network because the same information is re-propagated leaving less room for creativity and new ideas [9]. In academia, structural holes and lower density have a positive impact on research output and benefits the performance of the members of the network [25]. Moreover, researchers who hold a more central position in densely connected networks tend to create more knowledge [9]. We see evidence of this when we compared the egocentric networks of Steve Benford and Daniel Vogel. Referring to Figure 3, we see that the network is less dense with several structural holes and with Steve Benford acting as an information broker. We looked at the 8 papers that he published and they range across artistic smartphone apps [31], interactive design for musical and gaming systems [13], interactivity in film [29], performative mirrors [15], musicians' interactive preparation [24], reflections on ideation cards [8] etc. The central theme around these papers is arts but they develop and employ a diverse set of technologies. This breadth of different ideas depicts that Steve Benford is playing a vital role in his network when it comes to new knowledge creation.

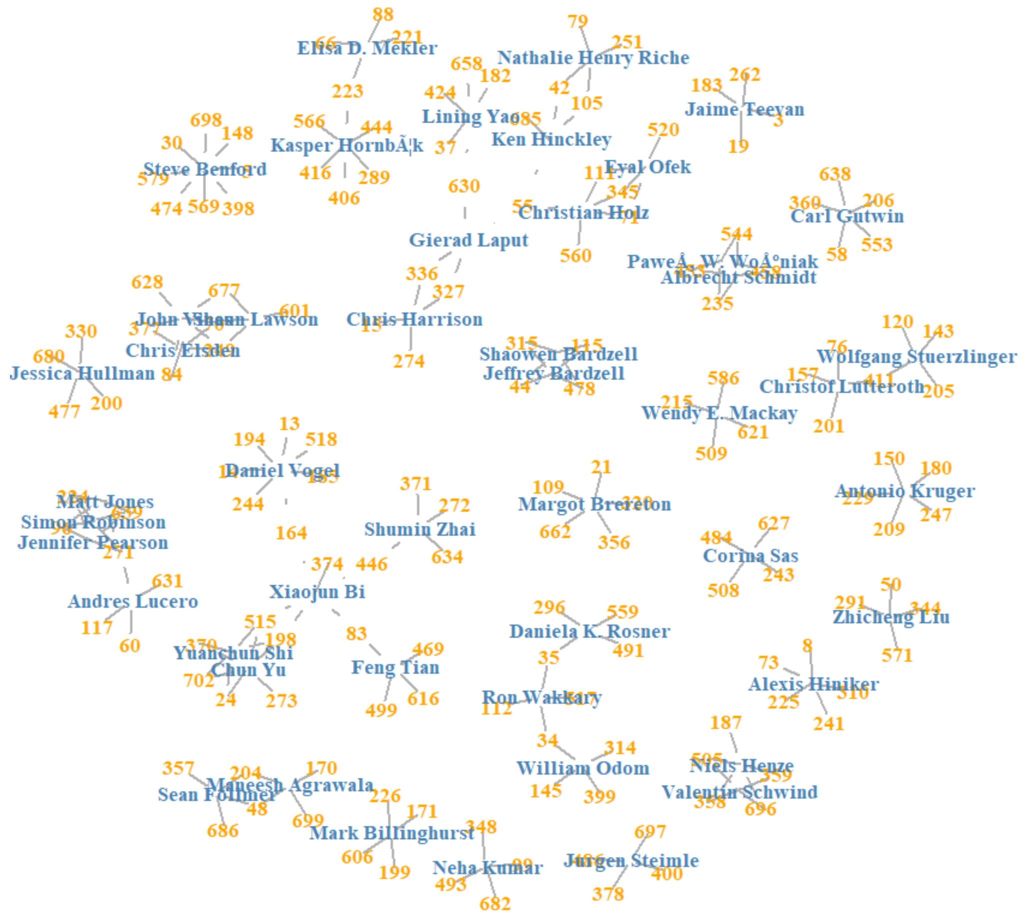

Figure 6: Authors with more than 5 publications in CHI 2019

As depicted in Figure 4, Daniel Vogel's egocentric network is well connected. All the papers published by Daniel Vogel focused on virtual reality [32, 33] and gesture control [7, 10, 16, 17]. This is undoubtedly an important area of research but we see these technologies being applied in the same contexts limiting the creativity of the network as a whole. Irrespective of the network structures, the presence of central figures with significant power increases the social capital of researchers connected to them. It is imperative to remember that CHI is the premier conference for Human-Computer Interaction research. Central figures not only help create new knowledge but they also help situate the current work within the HCI community, that is, they impart their knowledge on how the current work can further the research and benefit the HCI community. In other words, researchers need the guidance of central figures to write successful CHI papers.

Which institutions collaborate together (RQ2) and why (RQ3)?

Our results depict two dominant areas of HCI research within the CHI community. There are organizations that are focusing more on the social implications of the technology and it impact on people and their work, that is, ***socially-driven*** human-computer interaction. Our network models in combination with our topic models reveal that University of Washington (60 publications) is the first epicenter for socially-driven HCI research followed by University of Michigan (27 publications). Relatively smaller and newer HCI schools such as Northwestern University and University of Colorado Boulder have been able to increase their contributions to the CHI community over the last 5 years by hiring graduates from University of Washington and University of Michigan, thereby, developing collaborations with these schools. We also see that University College London collaborated with University of Washington, University of

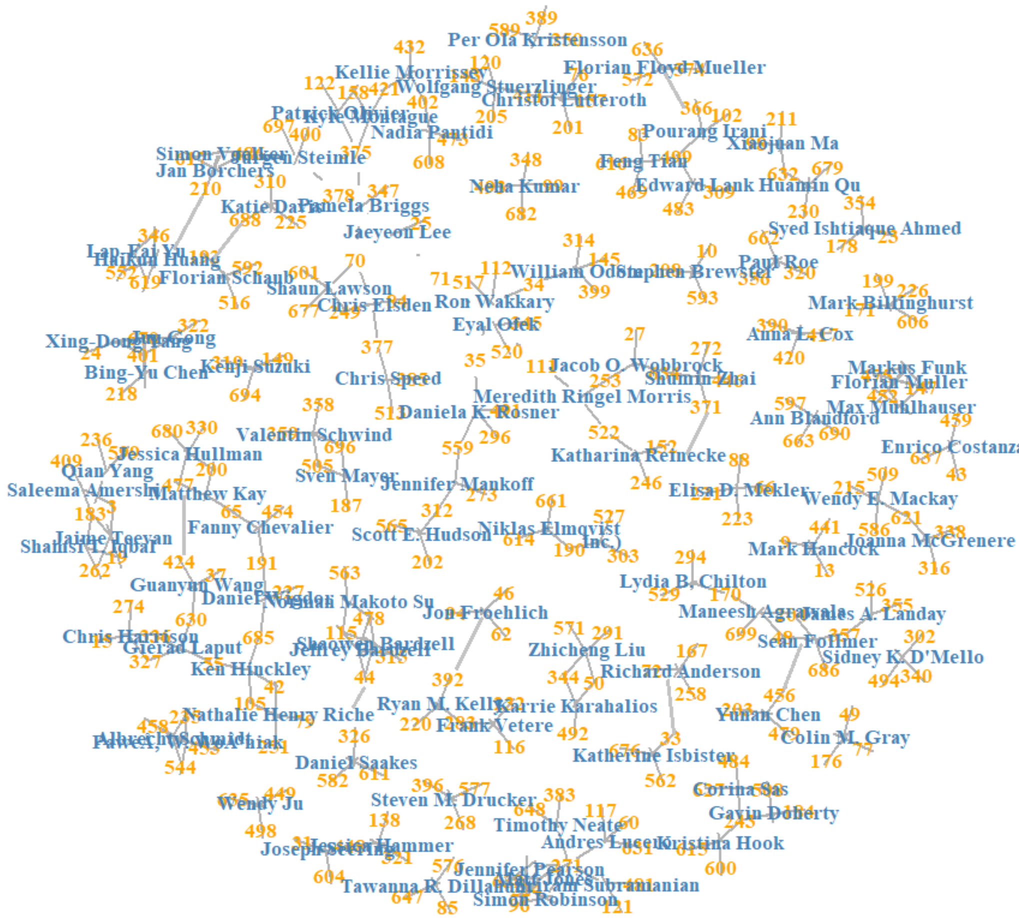

Figure 7: Authors with 3 or 4 publications in CHI 2019

Michigan, as well as Northwestern University which led to more publications.

The second dominant area of research within the CHI community focuses more on ***technically-driven*** human-computer interaction. This is not to say that the contributions of socially-driven HCI research are less "technical". This distinction focus on the broader perspective of the contributions and motivations of researchers. Socially-driven HCI research makes contributions around the use to technology in the society and improving lives of people. Technically-driven HCI research focuses more on design of technologies to improve interactivity, such UX design, gesture control design, and virtual reality. Carnegie Mellon University and Stanford University are the two epicenters of technically-driven HCI in the United States followed by Korea Advanced Institute of Science and Technology (KAIST) and University of Waterloo in Canada.

Does (not) collaborating hurt research productivity?

Our results revealed another important question around collaborations. Given the research domain, we expected to find collaborations between some universities but they did not exist. For instance, both KAIST and University of Waterloo are working extensively on Virtual Reality , Gesture Control, and Human-Robot interaction. However, these two organizations did not collaborate on any papers. General principles of sociometry state that a new player in a social network must try and connect with a central figure to be able to gain some social capital and grow their own connections [5]. However, both University of Waterloo and KAIST are comparable and self-sufficient institutions with each organization publishing 14 papers at CHI 2019. Moreover, research on social networks in academia suggests that such structural holes are necessary to improve research output and creation of new knowledge. We saw evidence of this when we reviewed the papers published by both universities. Both universities made unique contributions to the field of virtual reality, gesture control, and human-robot interactions which are depicted in Table 2. By not collaborating, these two self-sufficient schools are contributing more novel research to the CHI community. This is a good example of a network where network closure and brokerage benefits the performance of the members of the network. That is, the homogeneity of information, new ideas, and behavior is generally higher within any one group of people as compared to that in between two groups of people [5].

6 FUTURE WORK

We wanted assess what proportion of women researchers constitute the HCI community. To accomplish this, we captured the name of all HCI researchers who authored a paper in CHI 2019 and then we used the gender package in R which assigns a binary gender to each person. We experienced ethical as well as data integrity concerns in regards to this task. First, the gender package uses historical data of western names to assign a gender to a name. This package failed to correctly recognize the gender of several names of non-Western origin. Second, there are researchers in the HCI community who associate themselves with a non-binary gender, and therefore, it would be unethical on our part to try to push their names into one of the binary "bins". Understanding the development of women researchers' social capital in different academic circles is in itself an open area of research [4] and offers future research opportunity to explore this within the HCI community. Moreover, we conducted a static analysis of CHI 2019, however, a longitudinal analysis over a period of 10 or more years would reveal more useful insights about the development of new HCI departments at universities as well as the evolution of collaborations.

7 LIMITATIONS

This research study mostly focuses on the epicenters in the CHI community within the United States even though smaller network structures outside the U.S. could equally reveal pertinent information about specific communities within CHI. We see a glimpse of that with the CHI community in western Europe. This study is also a static analysis of the CHI community in 2019. A longitudinal analysis of how the CHI community has evolved over time would reveal useful insights into how HCI research has grown over time. For instance, University of Colorado Boulder has a relatively new HCI research department but it has now grown into a significant contributor at CHI.

8 CONCLUSION

We examined the Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems and we were able to gain some valuable insights into the HCI community and its practices. Our network graphs revealed the epicenters of HCI research around the world but we focused our attention towards understanding the network structures related to two HCI epicenters in the United States. Our analysis shows the top organizations that are collaborating with these schools. Moreover, our topic models reveal the context under which these collaborations are taking place. Network science helped us reveal the underlying network structures within the CHI community but topic models allowed us to offer context to these networks. Knowledge from these topic models will be used in the future to future refine the network models.

Furthermore, we analyzed the HCI researchers to reveal both the most publishing as well as the most collaborative authors in the CHI community. We demonstrate who the most important information brokers are and who they collaborate with. Information brokering is generally understood in terms of a knowledge broker who develops relationships by providing linkages (knowledge sources). However, in terms of academia, pertinent information brokers lead to the creation of new knowledge.

Finally, our topic models reveal the context under which different organizations collaborate with the two HCI epicenters within the United States. HCI researchers at the University of Washington engage more in socially-driven HCI research, that is, understanding the role and influence of technology in the society, government, and people. HCI researchers at Carnegie Mellon University, on the other hand, engage in more technically-driven HCI research. For example, developing explainable algorithms and interactive systems.

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University of Waterloo	KAIST
Gesture Control	
1. RotoSwype: Word-Gesture Typing using a Ring [10]	1. Diagnosing and Coping with Mode Errors in Korean-English Dual-language Keyboard [23]
2. HotStrokes: Word-Gesture Shortcuts on a Trackpad [7]	2. TORC: A Virtual Reality Controller for In-Hand High-Dexterity Finger Interaction [22]
3. An Evaluation of Touch Input at the Edge of a Table [16]	3. Like A Second Skin: Understanding How Epidermal Devices Affect Human Tactile Perception [26]
4. Leveraging Distal Vibrotactile Feedback for Target Acquisition [14]	
5. PinchList: Leveraging Pinch Gestures for Hierarchical List Navigation on Smartphones [11]	
Human-Robot interaction	
1. Expression of Curiosity in Social Robots: Design, Perception, and Effects on Behaviour [6]	1. Slow Robots for Unobtrusive Posture Correction [30]
Virtual Reality	
1. TabletInVR: Exploring the Design Space for Using a Multi-Touch Tablet in Virtual Reality [32]	1. TORC: A Virtual Reality Controller for In-Hand High-Dexterity Finger Interaction [22]
2. Experimental Analysis of Barehand Mid-air Mode-Switching Techniques in Virtual Reality [33]	2. Evaluating the Combination of Visual Communication Cues for HMD-based Mixed Reality Remote Collaboration [18]
3. RealityCheck: Blending Virtual Environments with Situated Physical Reality [12]	3. VirtualComponent: A Mixed-Reality Tool for Designing and Tuning Breadboarded Circuits [19]
4. Quantitative Measurement of Tool Embodiment for Virtual Reality Input Alternatives [1]	4. Geometrically Compensating Effect of End-to-End Latency in Moving-Target Selection Games [21]
	5. SmartManikin: Virtual Humans with Agency for Design Tools [20]

Table 2: Publications by University of Waterloo and KAIST that make unique contributions to gesture control, human-robot interaction, and virtual reality.

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A TOPIC MODELS

	User Engagement	Virtual Reality	Security & Privacy	Interaction Design	Quantitative Study	USer interaction with VR	User Study	Ethnography	Design Checklist	Technology for human services
	Topic # 01	Topic # 02	Topic # 03	Topic # 04	Topic # 05	Topic # 06	Topic # 07	Topic # 08	Topic # 09	Topic # 10
0	studi	user	user	design	user	design	design	user	design	design
1	work	object	secur	research	design	support	user	design	student	user
2	design	interact	design	studi	interact	visual	studi	studi	user	game
3	peopl	hand	virtual	base	studi	experi	interact	interact	studi	studi
4	data	experi	object	user	result	interact	human	data	learn	social
5	support	design	studi	learn	base	research	devic	gestur	experi	experi
6	particip	social	data	particip	accuraci	work	work	experi	technolog	particip
7	experi	studi	shape	paper	model	develop	present	perform	develop	interact
8	visual	method	process	interact	enabl	user	mobil	provid	data	present
9	person	virtual	develop	model	method	posit	result	inform	time	provid
10	technolog	result	challeng	technolog	experi	provid	challeng	peopl	social	virtual
11	effect	gestur	privaci	data	data	process	person	feedback	access	control
12	find	support	peopl	experi	technolog	base	experi	paper	result	share
13	paper	bodi	valu	practic	present	studi	interfac	particip	paper	communiti
14	onlin	peopl	digit	support	particip	explor	time	base	educ	research
15	present	paper	interact	tool	evalu	adult	paper	result	base	play
16	discuss	techniqu	haptic	differ	gaze	space	effect	activ	present	support
17	research	effect	techniqu	analysi	creat	data	inform	devic	trust	find
18	inform	devic	devic	result	tool	result	visual	time	support	technolog
19	result	base	experi	devic	inform	increas	base	research	practic	result

Figure 8: Topic modeling all abstracts of papers published at CHI 2019

	Technology for human services	User Engagement	Smart Device for a family	PD for children	Understand needs of users	User engagement	User awareness about security	Contextual factors	Design Checklist	Technology for human services
	Topic # 01	Topic # 02	Topic # 03	Topic # 04	Topic # 05	Topic # 06	Topic # 07	Topic # 08	Topic # 09	Topic # 10
0	design	sound	design	children	patient	design	data	studi	design	touch
1	label	design	home	technolog	raid	user	warn	context	patient	user
2	home	studi	collabor	design	base	base	student	sound	checklist	accuraci
3	find	phone	devic	creepi	care	interact	accuraci	design	activ	peopl
4	onlin	particip	smart	studi	understand	data	discuss	particip	care	paper
5	servic	awar	technolog	famili	technolog	translat	design	self	research	analysi
6	access	peopl	user	fear	design	applic	phish	awar	support	perform
7	food	rumor	particip	communic	group	clench	scienc	technolog	hemodialysi	metric
8	studi	paper	system	user	format	practic	breach	contextu	identifi	speed
9	potenti	compuls	role	concern	support	research	earli	relat	peopl	entri
10	system	user	trust	examin	need	provid	deploy	care	self	text
11	healthi	home	studi	digit	dynam	develop	applic	visual	valu	forum
12	user	experi	behavior	interview	user	paper	inform	onlin	provid	report
13	street	help	school	particip	interact	techniqu	argument	frame	includ	voic
14	group	relat	drive	social	portal	experi	action	system	decis	research
15	tappabl	find	work	repair	interview	audio	link	peopl	interview	cluster
16	work	base	parent	system	social	interview	understand	provid	outlin	robot
17	groceri	system	peopl	physic	brush	virtual	user	factor	implement	throughput
18	tool	prototyp	term	implement	game	student	email	conduct	system	exampl
19	investig	approach	interview	relationship	player	work	find	type	diagnost	particip

Figure 9: Topic modeling abstracts of papers published by University of Washington and its top collaborators at CHI 2019

	Engineering Design Process	Privacy Algorithm	Gaming Platform	Quizbot Clinician	Wearable devices	VR Haptic Feedback	Pedestrian guidance system	Rehab devices Haptic feedback	Improving computer hardware	Social Robot
	Topic # 01	Topic # 02	Topic # 03	Topic # 04	Topic # 05	Topic # 06	Topic # 07	Topic # 08	Topic # 09	Topic # 10
0	object	channel	time	learn	design	haptic	user	feedback	design	task
1	interact	support	design	fabric	posit	quadcopt	communiti	user	line	design
2	print	self	career	design	experi	interact	role	design	actuat	robot
3	materi	secur	onlin	student	electron	devic	member	question	base	messageontap
4	fabric	privaci	share	studi	wearabl	virtual	particip	haptic	print	text
5	strong	peopl	applic	quizbot	approach	accuraci	sound	peer	surfac	studi
6	result	purchas	game	result	interact	hand	support	robot	paper	cat
7	data	decis	social	flashcard	increas	type	pedestrian	visual	space	behavior
8	creat	public	platform	clinic	tool	challeng	differ	process	morph	use
9	devic	devic	chang	technolog	bodi	experi	time	type	heat	user
10	fiber	privat	interact	factual	compon	self	studi	write	comput	convers
11	techniqu	disclosur	chatbot	knowledg	high	techniqu	predict	pattern	model	suggest
12	function	group	goal	creat	function	control	notif	improv	materi	textur
13	emb	health	model	clinician	fabric	passiv	collis	receiv	soft	creat
14	mechan	level	behavior	investig	inform	hover	nearbi	blend	shape	interfac
15	scientist	algorithm	request	support	conform	realiti	bbeep	generat	textur	paint
16	design	street	effect	techniqu	activ	rich	base	walk	doubl	paramet
17	sens	concern	research	bodi	access	encount	onlin	better	curvatur	express
18	process	report	player	sens	challeng	object	futur	human	continu	video
19	high	disclos	develop	particular	limit	hoverhapt	investig	paper	fabric	conduct

Figure 10: Topic modeling abstracts of papers published by Carnegie Mellon University and its top collaborators at CHI 2019

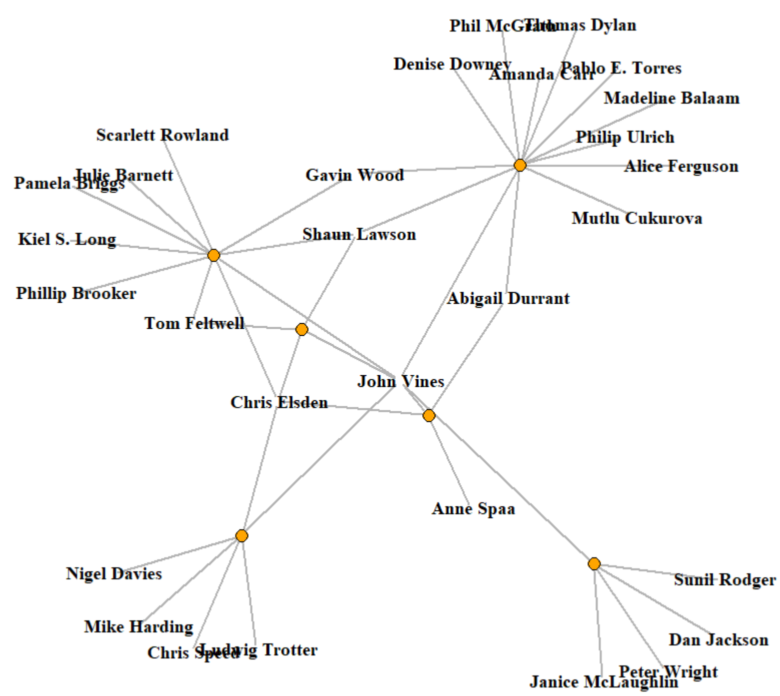

Figure 11: John Vines' egocentric network