# The Pervasive Technology Institute at 20: Two decades of success and counting

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PERVASIVE TECHNOLOGY INSTITUTE
INDIANA UNIVERSITY

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## Executive Summary

The Indiana University Pervasive Technology Institute (PTI)[1] has evolved from its inception in 1999 as the Indiana University Pervasive Technology Labs into a large and vital collaborative organization that provides leadership, resources, and services in computer science, informatics, information technology, and cyberinfrastructure.

> The Indiana University Pervasive Technology Institute (IUPTI) transforms new innovations in cyberinfrastructure, computer science, and information technology into robust tools enabling new breakthroughs in research, scholarship, and artistic creation; delivers such tools and supports their use in academic and private sector contexts; aids the growth of the Indiana economy; and helps build Indiana's 21st century workforce.

PTI is engages in five major activities:

- Creating knowledge, inventing technology, and supporting creativity
- Supporting and sustaining delivery of value from new technology inventions:
  - PTI transforms new technology from "successful proof of concept" to "widely used R&D tool in academia and research"
  - PTI provides, supports, enhances, and maintains hardware and software
- Leading or supporting the commercialization of Indiana University-developed technology
- Serving the state of Indiana
- Aiding PTI-affiliated Centers, and developing new centers and areas of excellence within Indiana University

In terms of size, PTI is in the second tier of cyberinfrastructure centers nationally; it is, however, at the forefront of the tier regarding quality. PTI's accomplishments to date include1,300+ technical publications, $90M+ in grant funding to Indiana University, $30M+ in active awards to the Office of the Vice President for Information Technology and CIO (OVPIT), and leadership in securing large awards ($10M+).

[1] https://pti.iu.edu/

## 1. Introduction

In 1997, Myles Brand, the 14th President of Indiana University, challenged the university to become "a leader [among institutions of higher education], in absolute terms, in the use and application of information technology."[2] The Indiana University Pervasive Technology Institute (PTI), initially called the Pervasive Technology Labs (PTL), was founded in 1999 to help IU achieve this goal. Indiana University, by any rational measure, has succeeded working at the forefront of the use and application of information technology.

PTL was initiated thanks to a $30M grant from the Lilly Endowment in 1999. Second-round funding of $15M in 2008 led to the current structure of the Pervasive Technology Institute. At the time of the 2008 award, President Michael A. McRobbie praised PTI's inception, noting that "creating the Pervasive Technology Institute is the logical next step to securing our position of leadership in the information technology field and will serve as a catalyst to our efforts to expand all of our research enterprises within the university and state."

PTI excels in research in computing, and in supporting computing resources for research, scholarship, and the arts. Collectively, the range of hardware, software, and human resources within the purview of PTI's expertise is now commonly referred to as "cyberinfrastructure"—a word popularized but never fully explained by the National Science Foundation. PTI created the now standard definition: "Cyberinfrastructure consists of computing systems, data storage systems, advanced instruments and data repositories, visualization environments, and people, all linked together by software and high-performance networks to improve research productivity and enable breakthroughs not otherwise possible."[3] PTI's mission, within and beyond Indiana University, is to create cyberinfrastructure, and to enable innovation through cyberinfrastructure.

Through its affiliation with the Research Technologies Division of University Information Technology Services, PTI offers significant computational, storage, and visualization cyberinfrastructure resources. PTI offers services that one would not term supercomputing - including services for digital humanities, biology, and areas of security research and service. PTI likewise differs from organizations that focus exclusively on software such as the University of Southern California's Information Sciences Institute.[4] PTI is a peerless organization; there is no other organization quite like it.[5]

PTI plays a critical role in Indiana University's overall strategy of leadership in information technology, computer science, advanced cyberinfrastructure, and high performance computing. Just as a stool rests solidly on three legs, Indiana University's strategy in information technology, advanced computing, and cyberinfrastructure rests on three essential strengths:

1) Outstanding basic research in computer science, informatics, and engineering. These activities are led by Indiana University faculty, primarily from the School of Informatics, Computing, and Engineering, as well as the Maurer School of Law, the College of Arts and Sciences, the Kelley School of Business, and the Purdue School of Engineering at IUPUI.

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[2] Dunn, J. Michael, & McRobbie, Michael. (1998). *Information technology strategic plan: Architecture for the 21st century.* Indiana University. http://hdl.handle.net/2022/471

[3] NSF Advisory Committee for Cyberinfrastructure Task Force on Campus Bridging. *Final Report*. March 2011. Available from: https://vdocuments.us/download/national-science-foundation-advisory-committee-for-cyberinfrastructuretask-force-on-campus-bridging-final-report-march-2011 cites Stewart, C.A., S. Simms, B. Plale, M. Link, D. Hancock and G. Fox. What is Cyberinfrastructure? In: Proceedings of SIGUCCS 2010. Norfolk, VA, 24-27 Oct, 2010. in its definitional work around the word "cyberinfrastructure."

[4] Information Sciences Institute: University of Southern California School of Engineering. (2018). Retrieved from https://www.isi.edu

[5] Please see Appendix 3 for a comparison of PTI and its closest analogs within the U.S.

2) Ground-breaking research, development, and delivery functions transforming new innovations into significant tools, aiding the research, scholarly, and artistic communities of Indiana University and the U.S., and in the process fostering the Indiana economy. These activities are the focus of PTI.
3) Exceptional cyberinfrastructure and staff supporting that infrastructure. These activities are led by the Research Technologies Division of University Information Technology Services, and by UITS generally in activities beyond collaboration with PTI.

The purpose of this document is to explain to audiences within and beyond Indiana University the purpose and activities of Pervasive Technology Institute, its accomplishments over the first twenty years of its existence, and its current activities. Audiences for this document include:

- The Indiana University community, particularly so that this community can better leverage PTI's personnel and capabilities
- Lawmakers, business leaders, and the public within the State of Indiana
- Leaders in the private sector, particularly leaders of IT firms nationally, and manufacturing and IT firms with a strong presence in the State of Indiana, so that they can take advantage of collaborations with PTI and understand the value PTI adds to the state's economy
- Members of the scientific community nationally, as well as program officers at federal funding agencies, so that they become more aware of the breadth and impact of PTI's activity
- Undergraduate students, so that they consider and enroll in Indiana University for graduate study
- Highly-skilled IT and cyberinfrastructure professionals, so that they consider Indiana University as a potential employer

### *1.1. PTI: a collaborative, interdisciplinary organization*

> *The mission of the Indiana University Pervasive Technology Institute (IUPTI) is to transform new innovations in cyberinfrastructure, computer science, and information technology into robust tools enabling breakthroughs in research, scholarship, and artistic creation; deliver such tools and support their use at academic institutions and in the private sector; accelerate the growth of the Indiana economy; and help build Indiana's 21st century workforce.*

The word "pervasive" in the name Indiana University Pervasive Technology Institute reflects the foundational importance of computer science, informatics, cyberinfrastructure, and information technology research to academic and industrial activities today.

PTI's distinctive structure was designed to enable its persistence over time while remaining responsive to the needs of various communities. PTI consists of a core support and organizing functions, and a set of affiliated centers. Each center is, in turn, a collaborative organization involving participants from two to several disciplines. The solutions to many important problems often require collaboration across disciplinary boundaries of academia. Within Indiana University, PTI enables such collaboration, fostering rapid responses to the needs of academia, society, industry, and business.

PTI operates on the philosophy that credit, unlike matter and energy, is a non-conserved property. One does not have less of it as a result of sharing it. This approach fosters a highly collaborative atmosphere—a foundational element of PTI's success. This philosophy breeds collaboration among centers with highly diverse foci, and fosters partnerships within the Indiana University, state, national, and international research communities. PTI, as an organization, is intended to persist over time while individual centers are expected to form, stay active for a period of time, and disband when they no longer provide practical benefit to the university or nation.[6]

[6] Appendix 1 includes a list of centers formerly affiliated with PTI.

PTI's unusual positioning within Indiana University's overall organization is a critical aspect of its success. Within the OVPIT, PTI is distinct from the university's information technology services organization, University Information Technology Services (UITS), though it includes, by affiliation, the UITS division of Research Technology. PTI does more exploratory and development work than an organization with "Information Technology Services" in its title could easily justify. At the same time, PTI does more work in application and support of cyberinfrastructure than could easily be done within the mission and reward structure of an academic school or department.

PTI is led by an Executive Director. Each of the directors of PTI-affiliated centers have the title of Associate Director, indicating their role in the leadership and governance of PTI. Center directors may also, at their discretion, appoint leaders within their own centers with the title of Assistant Director, PTI.

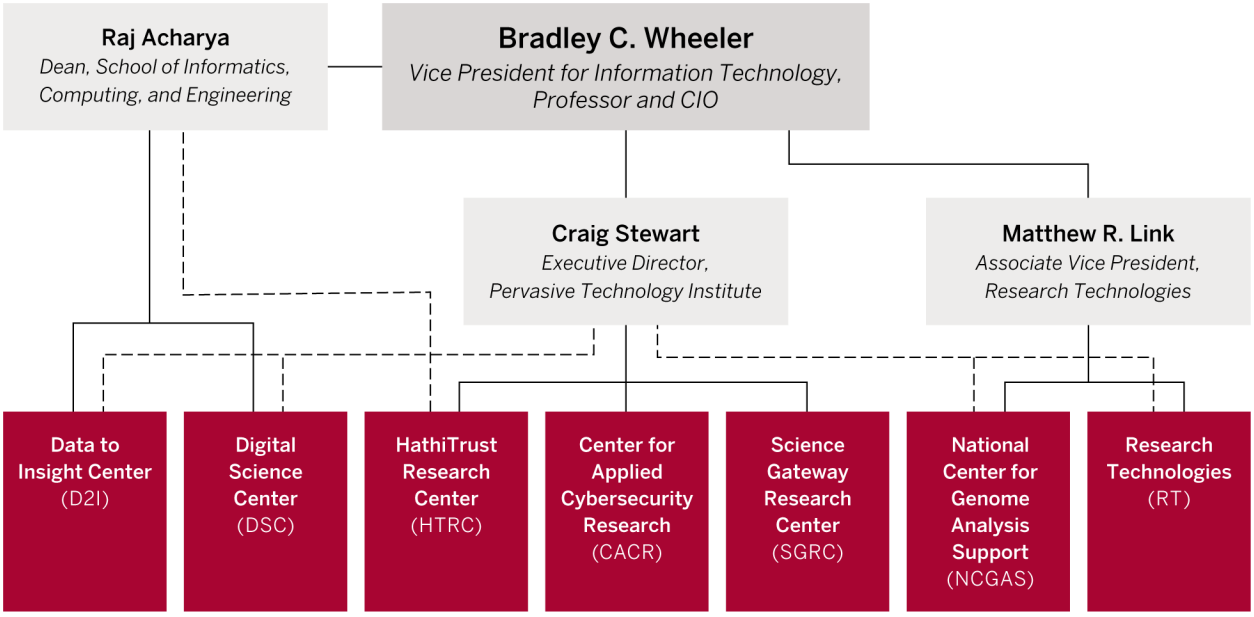


**Figure 1-1 Organizational structure of PTI as of November 2018.**

In keeping with its mission as a collaborative organization, PTI engages many stakeholders in its activities and successes. They are listed below and organized in terms of decreasing direct financial engagement:

- **Office of the Vice President for Information Technology (OVPIT)** provides the "administrative home" for PTI, invests strongly in PTI, and reaps financial benefits from PTI grant awards. OVPIT receives significant income as a result of PTI grant funding and Indiana University's practice of distributing the majority of Facilities & Administration (F&A) monies back to the responsibility center with which a grant award is associated. By state law, such F&A monies are the source of debt service for the Cyberinfrastructure Building mortgage.
- **School of Informatics, Computing, and Engineering (SICE)** provides the primary affiliation for two of the current PTI centers, and supports PTI through salary, support for faculty members, space, and F&A return agreements for SICE-led centers.
- **Maurer School of Law, Kelley School of Business, and the College of Arts and Sciences** partner with and support PTI through faculty collaboration.
- **The Indiana University research, scholarly, and artistic communities** contribute to and benefit from PTI's activities through collaboration and access to tools and services.

- **Businesses that operate within Indiana and throughout the U.S.** offer key collaborations assisting with PTI's mission to enhance the Indiana state economy. Current collaborations include joint F&ED efforts with Rolls Royce and Cummins.
- **The populace of Indiana and the U.S.** benefit from PTI's innovations, economic development, and STEM workforce development. The taxpayers of Indiana support PTI through the portion of their tax payments allotted to Indiana University.

### *1.2. The two Valleys of Death*

Each week, new academic papers and software releases herald the creation of a new prototype for a piece of software or cyberinfrastructure service. Most of these tools fulfill some interesting and potentially innovative function, but few ever have a useful life that extends beyond the publication of an academic paper or perhaps the depositing of the prototype's code in a code repository. The difficult path from *initial success as an idea* to *success as a widely used product* is often referred to as "the valley of death." Many new ideas enter; few survive the climb up the other side.

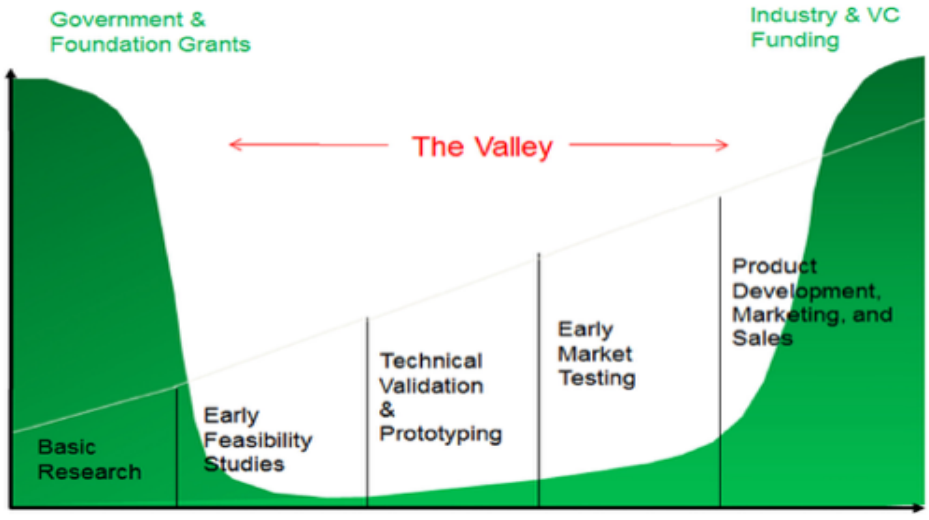


**Figure 1-2. Schematic diagram of the so-called "valley of death."**

National Academies of Sciences, Engineering, and Medicine. 2016. A Vision for the Future of Center-Based Multidisciplinary Engineering Research: Proceedings of a Symposium. Washington, DC: The National Academies Press. https://doi.org/10.17226/23645.

However, embedded within the "Basic Research" segment of the figure above are two very distinct activities:

- Conceptualization of a new technology, service, or piece of software and the realization in the form of an experiment or demonstration that constitutes a successful "proof of concept."
- Conversion of a new technology from "proof of concept" into a tool actually used within research and development communities.

Thus, as pointed out in testimony given before Parliament in the United Kingdom,[7] it is more appropriate to think of technology development as involving two valleys of death, as shown below in

Figure **1-3**.

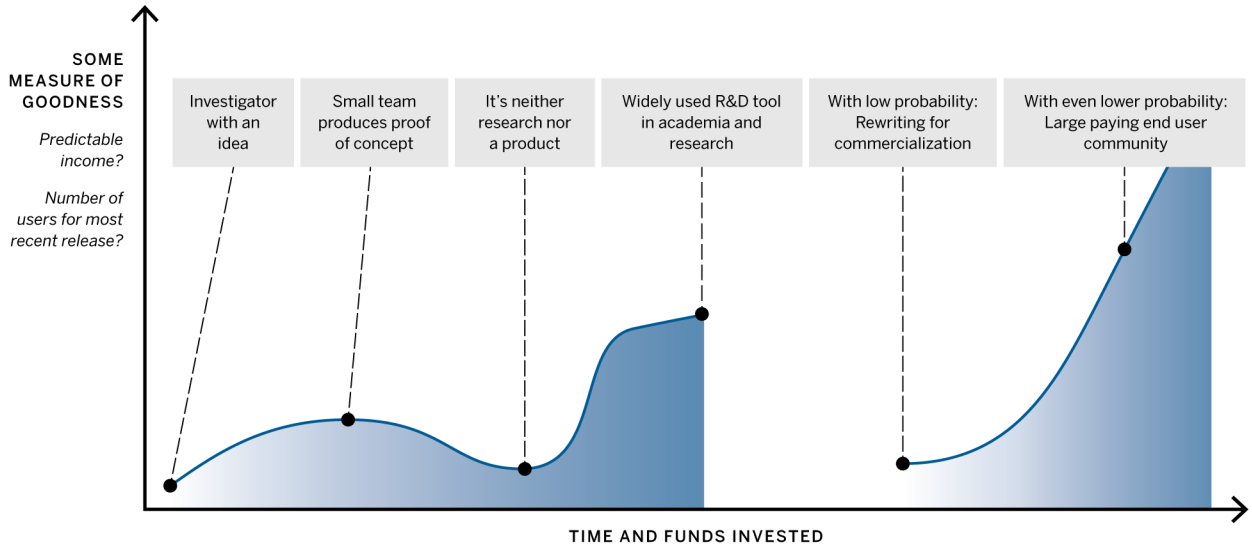


**Figure 1-3. Two valleys of death in the life of a new technology innovation and maturation, based on a figure from a document written by the Royal Aeronautical Society.**

Three of PTI's major functions relate to technology innovation and maturation and have to do with the evolution of technology along these valleys of death, as shown in the figure below. First, PTI creates new technologies and services. PTI spends much of its effort identifying new ideas—from Indiana University and elsewhere—through the first valley of death to convert them into mature and widely-used tools and services within the academic research and development community. When appropriate, PTI also becomes directly involved in commercializing new technologies developed at Indiana University, as depicted in **Error! Not a valid bookmark self-reference.** below:

[7] Royal Aeronautical Society. (2012). *Written evidence submitted by Royal Aeronautical Society*. https://publications.parliament.uk/pa/cm201213/cmselect/cmsctech/348/348we03.htm

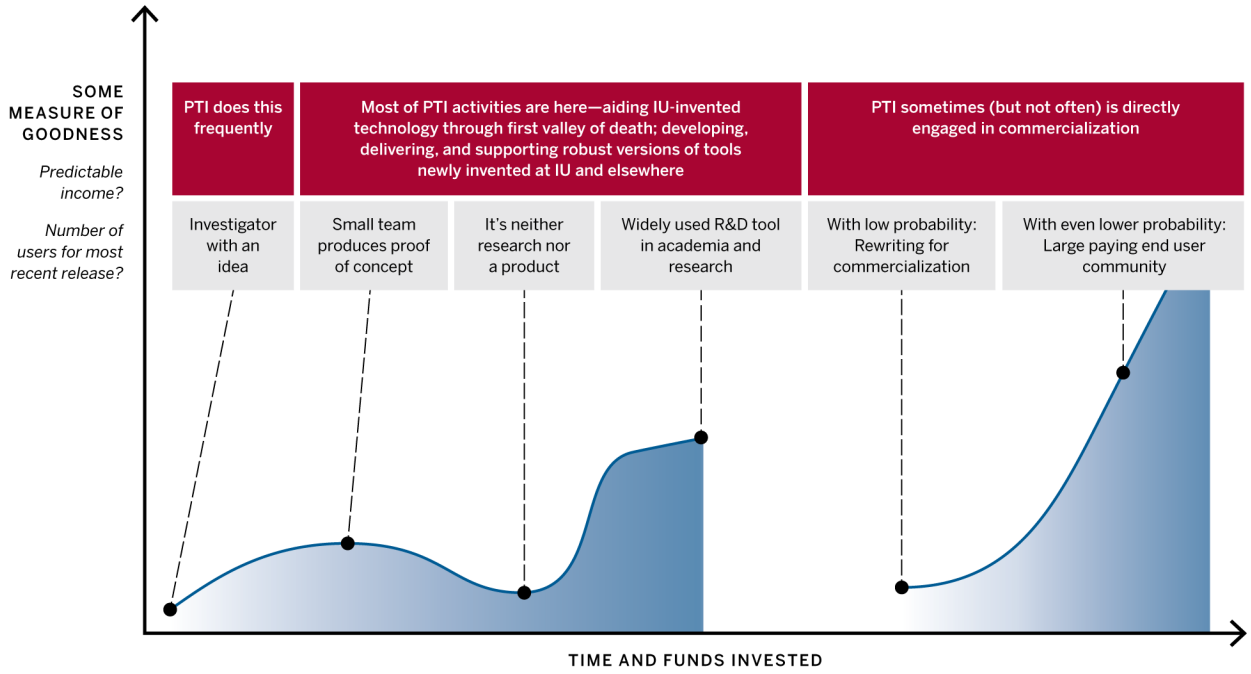


**Figure 1-4. PTI's roles in traversing the two valleys of death**

## *1.3. PTI's five major activities*

PTI engages in the following actions:

1) **PTI creates knowledge, invents technology, and supports creativity.**
    a. PTI supports the production of knowledge, scholarly works, and artistic creations.
    b. PTI often supports the implementation of, or hosts, important conferences and meetings in the sciences, humanities, and arts.[8]
2) **PTI supports and sustains delivery of value from new technology innovations.**
    a. PTI transforms new technology from "successful proof of concept" to "a widely used R&D tool in academia and research," bridging the gap between computer science and informatics research efforts and products usable by Indiana University and national research, humanities, and artistic communities. This competence is the source of much of PTI's funding success, as the institute is often tasked with developing services into production-quality software and/or hardware, and then delivering and supporting those services. This activity benefits the Indiana University community in several ways, including the following:
        i. Inventors of technology, tools, and services receive assistance transforming their inventions into the most useful and meaningful versions possible.
        ii. The Indiana University research, scholarly, and artistic communities benefit from earlier access to robustly usable versions of new innovations and services developed at Indiana University than their peers and competitors at other institutions.
    b. PTI provides, supports, enhances, and maintains hardware and software technologies as widely used R&D tools in academia and research. This activity often involves the implementation of new and novel hardware resources, including computational, storage, or visualization systems. PTI has enjoyed marked success in competing for federal grant funds for the delivery of cyberinfrastructure systems and services, and often receives federal

[8] One of Indiana University's Bicentennial Strategic Plan metrics includes the number of academic conferences held at Indiana University that bring scholars from other institutions to Indiana University. https://strategicplan.Indiana University.edu/plan/faculty.html#priority2

funding to develop, deliver, and support novel hardware systems and software tools delivered to the national research community. In both cases, new technology and tools are available at Indiana University, and grant funding helps expand the university's intellectual community.

3) **PTI leads and supports the commercialization of Indiana University developed technology**. When appropriate, PTI becomes directly involved in technology transfer to the private sector.
4) **PTI serves the state of Indiana.**
    a. PTI enhances the growth of the Indiana economy.
        i. PTI aids Indiana's economic growth by consulting with and providing resources to private sector entities. Some of these services are provided at no cost—through collaboration—to private entities in the state of Indiana, as part of Indiana University's mission to engage in the life of its home state.
        ii. PTI attracts talented, technically adept staff to Indiana, and keeps them happily funded by grants and contracts won through competition and brought into Indiana from outside the state. These highly-skilled staff members contribute to Indiana's workforce and tax base.
    b. PTI aids the development of a strong twenty-first century Science, Technology, Engineering, and Mathematics (STEM) workforce in Indiana and the U.S., drawn from native-born Hoosiers and others who readily adopt Indiana and the U.S. as their home. Indiana University's educational activities are driven primarily by the faculty and instructional staff. Though PTI does not offer any "for credit" classes within Indiana University, it arranges frequent non-credit training activities within the university, ranging from an hour to a few days in length. PTI also provides frequent outreach activities designed to interest young people in STEM careers, such as the annual "Robot Camp" offered each summer.[9]
5) **PTI aids PTI-affiliated Centers, and develops new centers and areas of excellence within Indiana University.**
    a. PTI often serves an "incubating function," helping new projects and initiatives grow into labs and then full-fledged PTI centers.
    b. PTI provides for the ongoing support and continuity of centers, sometimes through efforts such as routine delivery of support for grant writing, and sometimes through providing exceptional assistance to centers or labs that encounter periods of challenge in funding continuity.

### *1.4. PTI's research, development, and delivery agenda*

PTI enables a positive feedback loop in which Indiana University artist, scholar, clinician, engineer, scientist, and researcher needs drive the PTI research agenda. PTI then transforms computer science, informatics, and cyberinfrastructure innovations into high-quality, robust tools usable by the Indiana University, national, and international research communities. PTI's research agenda is also influenced by U.S. federal funding priorities, and PTI, in turn, influences U.S. national research priorities through its own actions and through its colleagues' work. Due to proximity and collegial communication, PTI creates a competitive advantage for Indiana University researchers in that inventions and innovations made here are used here first, before they are discovered by, and widely adopted at, other institutions. By supporting research interests in this way, PTI adds value to Indiana University, the State of Indiana, and the United States.

[9] UITS at Indiana University. (2015). *Ready, Set, Robots! Camp*. Available from https://www.youtube.com/watch?v=zWh9hWf0rBM&feature=youtu.be&list=PLqi-7yMgvZy8xB64_0-O7PId_uzTFy9PO

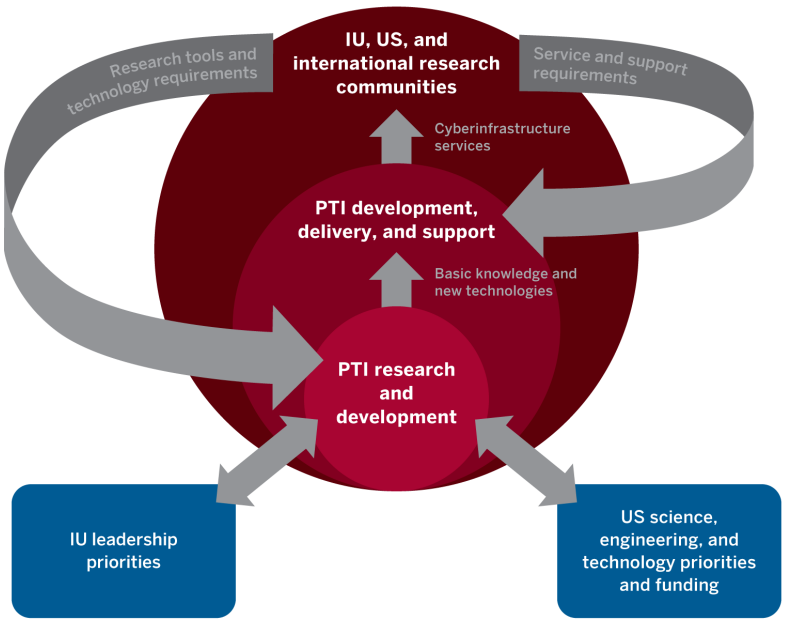


**Figure 1-5. PTI's research and services activities: what drives PTI's activities, and how PTI drives Indiana University capabilities and national agendas.**

PTI pursues grant funding related to cyberinfrastructure when it aligns with the following criteria:

- The work is of high value to funding agencies (federal and otherwise), and abides by policies. In other words, someone is willing to pay for it, and it is not classified.
- Indiana University has relevant faculty who can be involved as intellectual leaders.
- Indiana University employs experts who can do the technical R&D work required.
- When PTI staff who are not tenured or tenure-track faculty lead grant proposals, they are not pursuing grants that compete with tenured or tenure-track faculty.
- PTI can provide appropriate leadership, so that PTI staff are not competing with Indiana University faculty:
  - A PTI-affiliated faculty member serves as the Principal Investigator
  - Or a PTI professional staff member or NTT (Non Tenure-Track) academic appointee serves as PI when a particular opportunity seems better suited for a person in this role.[10]

## 2. Measures of PTI's success, at Indiana University and beyond

In the report to the Lilly Endowment summarizing the accomplishments of PTI through its second round of funding,[11] Indiana University offered a highly positive overall assessment of PTI's value and success. The purpose of this section is to update and expand upon prior reports with data that enable fact-based judgements of PTI's value.

[10] Some of the grants and contracts pursued and won by PTI involve situations in which a granting agency requires a level of control and commitment that exceeds what a tenured or tenure-track faculty member finds agreeable and consistent with their views of the role of a faculty member. PTI's focus on proposals led by professional staff members or non-tenured academic appointees can create a competitive advantage for Indiana University when pursuing such funding relative to grants led by tenured faculty who are perceived to have a high likelihood of becoming an "absentee PI."

[11] McRobbie, M.A. (2014). *Final Report to Lilly Endowment Inc.* Indiana University Pervasive Technology Institute. https://scholarworks.Indiana University.edu/dspace/handle/2022/19787

## 2.1. Metrics of success

Some of PTI's key metrics are summarized in Table 2-1 and Figure 2-1 below. To give a sense of PTI's scale and the evolution of PTI's size over time, PTI's predecessor—the section of UITS focused on research computing—employed only 24 people the year before Michael A. McRobbie arrived as Indiana University's first VP for Information Technology and CIO. As of the beginning of FY2019 (1 July 2018) there were a total of 115 FTEs working in PTI-affiliated centers: 70 FTEs were base-funded, and 45 FTEs supported by external contracts and grants.

| Metric | FY2018 | Total from inception to FY2018 |
|---|---|---|
| **Creating knowledge** | | |
| PTI Peer-reviewed Publications | 54 | 1,331 |
| Conferences hosted / led / supported | 1/1/3 | 18/22/3 |
| **Transforming new technology from "successful proof of concept" to "widely used R&D tool in academia and research"** | | |
| Number of new tools brought into service as widely used R&D tools | 35 | 594 |
| **Providing, supporting, enhancing, and maintaining hardware and software technologies as widely used R&D tools in academia and research** | | |
| Number of major services offered in support of R&D (not counting services offered by Research Technologies under funding primarily from Indiana University general funds accounts) | 31 | 82 |
| **Obtaining the means to support services** | | |
| PTI grant and contract $ from federal sources to OVPIT | $16,673,707 | $94,874,741 |
| PTI grant and contract $ from non-federal source to OVPIT | $1,306,690 | $10,936,867 |
| Currently active PTI grant awards to OVPIT | $17,980,397 | |
| PTI income from sources other than federal grants and contracts | $359,731 | $394,731 |
| **Commercializing Indiana University-developed technology** | | |
| Number of services being developed toward commercialization | 3 | 11 |
| Number of commercial licenses executed | 2 | 5 |
| Number of software packages released with open source licenses | 28 | 43 |
| **Enhancing the economy of Indiana and the US as a whole** | | |
| Active collaborations with Indiana's private sector | 3 | 17 |
| Person-years of employment created directly within PTI / Indiana University (actual grant headcount) | 30 years | 863 years |
| Job-years of employment in the State of Indiana created as a side effect of PTI grant awards as estimated by the IMPLAN methodology | 131 job-years | 532 job-years |
| Businesses operating in Indiana as an outgrowth of PTI funding or relationships | Added 1 | 6 |
| **Aiding the development of a strong 21st century Science, Technology, Engineering, and Mathematics (STEM) workforce in Indiana and the US** | | |
| Students receiving graduate degrees who worked in or were supported by a PTI-affiliated center | 3 | 143 |
| Awards won by students working with PTI | 1 | 4 |

**Table 2-1. Key metrics of accomplishment for the Indiana University Pervasive Technology Institute.**

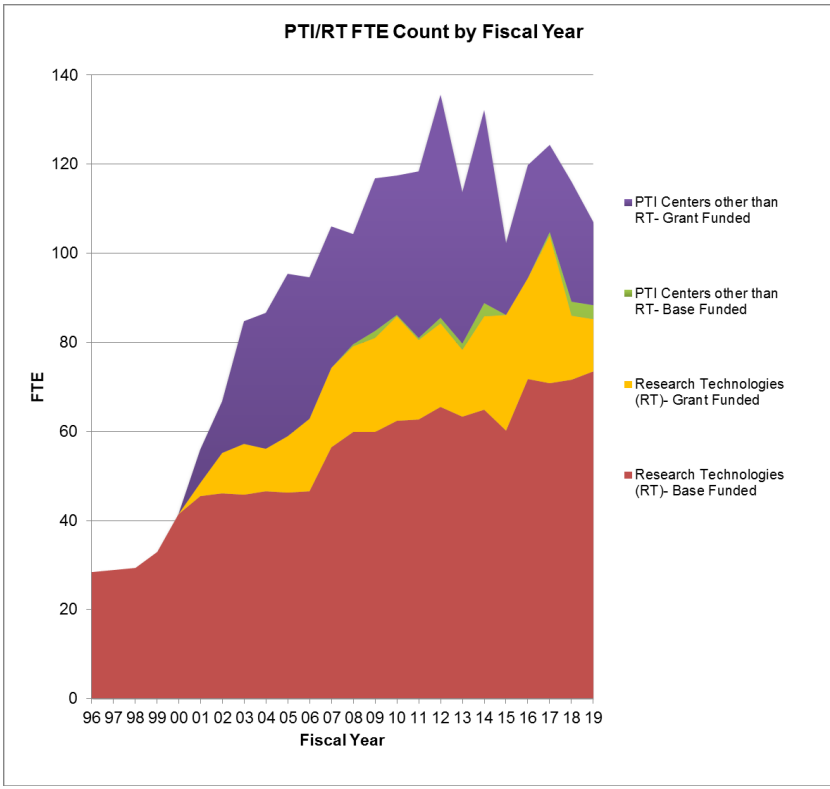


**Figure 2-1. Personnel and funding for the Pervasive Technology Institute showing base-funded and grant-funded staff.**

Research Technologies is shown separately from the remaining PTI centers because it has such a significant set of responsibilities to Indiana University funded by institutional monies. Of the grant- and contract-supported staff in Research Technologies, most are engaged in collaborative projects that involve one of the PTI centers or which were obtained with the aid of PTI in some fashion.

The above facts and figures present an affirmative picture of PTI's activities and accomplishments over time. Some particularly notable accomplishments include the following:

1) PTI creates knowledge, invents technology, and supports creativity.
    a. PTI aids Indiana University faculty members in competing for grants requiring extensive cyberinfrastructure support. Examples include the Data to Insight Center (D2I)'s involvement in the major NSF-funded project Sustainable Environment Actionable Data (SEAD), and the Digital Science Center (DSC)'s successes such as FutureGrid and PolarGrid. Beyond SICE, PTI also provided integral support to the College of Arts and Sciences and the Indiana University School of Medicine in securing grant funding. PTI has played an important part in IUSM's success in securing $75M in NIH funding for three successive grants through the Clinical and Translational Studies Awards. Indeed, during the initial $25M award period it was IndianaCTSI's progress in information technology services that distinguished this project from many others funded by the NIH. Particularly important in the early days of IndianaCTSI were services for handling and analyzing protected health data (PHI) offered by PTI. These early successes in services provided by PTI for IndianaCTSI facilitated what is now one of IU's most important grant awards in terms of impact on improving human health and quality of life.
    b. PTI aids the Indiana University community in competing for large grant awards. In the last fifteen years, Indiana University has won three major grants via the Clinical and Translational Studies Awards program of the National Institutes of Health (NIH), totaling $75M, each with significant support from PTI. Most of Indiana University's largest grants go to IUSM on the Indiana University-Purdue University Indianapolis campus. Large grant awards (in excess of $10M) are particularly valuable due to their wide scope, significant societal impact, and interdisciplinary approach to solving challenging problems. During this timeframe, there have

been only six grant awards to Indiana University Bloomington in an amount exceeding $10M. PTI is responsible for two of these six (FutureGrid and Jetstream).

2) PTI supports and sustains delivery of value from new technology inventions.
    a. PTI transforms new technology from "successful proof of concept" to "widely used R&D tool in academia and research."
        i. Perhaps the most striking example of recent achievement in this area is the Hathi Trust Research Center and the services it provides. An entire center and services used nationwide has been developed from what was initially a research idea within D2I.
    b. PTI provides, supports, enhances, and maintains hardware and software technologies as widely used R&D tools in academia and research.
        i. The Jetstream cloud system[12] remains one of the most notable, important, and widely used examples of novel hardware and software technologies deployed as a nationally-accessible, widely-used R&D tool.
        ii. The National Center for Genome Analysis Support (NCGAS) and Center for Applied Cybersecurity Research (CACR) have both proposed and received funding for delivery and support of software tools and expert cyberinfrastructure consulting; each is, in part, being funded to support the use of tools developed outside of Indiana University.
        iii. CACR has become one of the best funded cybersecurity research and service centers in the US. It leads four major cybersecurity services funded by the NSF, Department of Homeland Security, and the U.S. Navy.
    c. PTI leads or supports the commercialization of Indiana University-developed technology, when appropriate. Five pieces of PTI-developed technology have been successfully licensed to the commercial sector: one visualization system; one immersive virtual reality system; facial recognition software; a novel computer processor design; and navigation technology used in robotic lawnmowers.
3) PTI serves the state of Indiana.
    a. PTI enhances the growth of the Indiana and the United States economies.
        i. There are six small-to-medium sized businesses operating within the Indiana that are in the state because of, or with the support of, PTI.
        ii. Many of the open-source software tools created and distributed by PTI also support research in the private sector. Several Indiana industrial concerns make use of PTI-created open-source software, making good on the state's investment in IU and PTI.
        iii. Since the inception of PTL in 1999, PTL/PTI and Research Technologies have obtained grant funds totaling $94,874,741. With this money, PTI has added 836 FTE-years of employment to the Indiana University payroll. These are people that live in Indiana, shop in Indiana, and pay taxes in Indiana. This is an exact figure based on how many people have been employed with grant funds by PTI since 1999.
        iv. Based on IMPLAN methodology, we can estimate that PTI's collective efforts have created a total of 532 FTE years of employment in central Indiana through a combination of direct and indirect effects.[13]

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[12] Jetstream-cloud.org

[13] IMPLAN regional impact multiplier system (http://www.implan.com) estimates the total number of jobs created directly and indirectly as a result of grant income. It estimates, for example, how many jobs in the private sector of a given region are created as a result of having more customers in that region hired directly by out of state funding. One has to make a few assumptions to estimate full time equivalent jobs created in Indiana from PTI's grant successes. First, not all of the grant funds obtained by PTI stay inside the state of Indiana; purchases of computing hardware, for example, typically involve sending money to vendors outside of Indiana. Subcontracts on multi-party grant awards may also send grant funds out of state. Thus, we assume that one-third of the grant funds awarded to

b. PTI aids the development of a strong 21st century Science, Technology, Engineering, and Mathematics (STEM) workforce in Indiana:
    i. PTI's dissemination and outreach efforts reach more than 10,000 people per year. Through these efforts, PTI keeps Indiana, and the nation, abreast of Indiana University's research efforts, and encourages Indiana youth to consider STEM disciplines as college majors and career choices.
    ii. PTI is responsible for raising funds to support Science Node,[14] a free, online publication that explores the societal impact of advanced computing and networks. Science Node relies on PTI for fundraising and for its external subscription program, which reaches an additional 50,000 US residents.

4) PTI supports its affiliated centers, and cultivates new centers and areas of excellence within Indiana University.
    a. The creation of the Hathi Trust Research Center (HTRC) as a standalone center provides an outstanding example of the successful incubation of a new center.
    b. PTI enabled the creation of the Center for Research in Extreme Scale Computing (CREST) which, for a time, was a great success for Indiana University, bringing a total of more than $20M in grant funding to the university and creating many important innovations in computer science.
    c. During the last five years, PTI has investigated the creation of three new centers. In each of these cases, the idea at hand did not constitute the core of a center that could be viable primarily on the basis of funding external to Indiana University. However, each of these investigations resulted in new, smaller scale initiatives launched at Indiana University.

### *2.2. Notable 2018 successes*

In terms of aggregate grant wins, 2018 has been PTI's most fruitful year since Jetstream was funded in 2014. In recent months, the diversity of awards won has been particularly notable.

- Five major grant wins, a major contract, and expansion of prior awards for a total of more than $11M in new funding to PTI. PTI received five new awards from federal granting agencies: CACR (2 awards), NCGAS (1 award), and SGRC (2 awards). PTI also received a contract from the private sector (Microsoft, Inc.). The Microsoft contract, worth more than $1M, offers a notable example of PTI's success in increasing interaction with, and funding from, private industry. All PIs are OVPIT staff members.
- Of special note is the signing of a Cooperative Research and Development Agreement (CRADA) between Naval Surface Warfare Center (NSWC) Crane and CACR, with an associated grant award. In 2016, CACR established a collaborative relationship with NSWC Crane on cybersecurity, instantiated by a Cooperative Research and Development Agreement (CRADA).[15] This CRADA was renewed in September of 2018. This collaboration will bring $2M in funding to CACR. Indiana University now has a total of two CRADAs with Crane through CACR, accomplishing a previously unfulfilled objective of creating meaningful engagement between Crane and Indiana University.
- The Hathi Trust Research Center (HTRC) was created. The current Director of HTRC is Dr. John Walsh, a member of the Information and Library Science (ILS) department in SICE, an exceptional scholar, and a superb operational leader. HTRC is populated by staff with appointments in OVPIT.
- PTI strengthened collaborations in the following areas:

PTI have stayed within Indiana. We also assume also that one FTE is equivalent to four of the "jobs" that IMPLAN estimates to have been created per unit of external funding.

[14] www.sciencenode.org

[15] Indiana University Center for Applied Cybersecurity Research, NSWC Crane to collaborate on cybersecurity. (2016). Retrieved from https://itnews.Indiana University.edu/articles/2016/the-indiana-university-center-for-applied-cybersecurity-research-cacr,-naval-surface-warfare-center-crane-to-collaborate-on-cybersecurity.php

- Within Indiana University:
  - CACR led a grant proposal for one of PTI's biggest grant awards for the year. In an example of fruitful collaboration, a recent award to PTI was led by CACR and involved D2I and the OVPIT OmniSOC.[16] This same NSF solicitation resulted in another award (in a noncompeting subsection of the solicitation) led by the Science Gateways Research Center (SGRC).
  - CACR has strengthened ties to faculty in the Maurer School of Law and the Kelley School of Business.
  - NCGAS has strong ties to the College of Arts and Sciences (specifically the Department of Biology).
- Beyond Indiana University:
  - V4I (Virtual Verification, Validation, & Visualization Institute)[17] is a public-private partnership led largely by Indianapolis-based staff at Rolls Royce. PTI leads the V4I HPC group and stands to secure private sector contracts via its involvement in V4I. PTI and SGRC's engagement with V4I enabled SGRC and Marlon Pierce to obtain funding for the commercialization of SGRC software tools via the NSF Partnerships for Innovation program.[18]
  - NCGAS is a collaboration between PTI and the Pittsburgh Supercomputing Center.
- PTI-affiliated researchers received a total of three new grant awards to increase technology transfer activities. There was also one new startup created with a close link to PTI.

## 3. Conclusion and looking forward

The Pervasive Technology Institute began as an idea, backed by Indiana University's innovative spirit and an initial $30M investment from the Lilly Endowment, Inc. PTI has matured over nearly twenty years as part of a university-wide effort to achieve a goal set in 1997 by Myles Brand, the 14th President of Indiana University, to make the institution "a leader [among institutions of higher education], in absolute terms, in the use and application of information technology."[19] This goal seemed all but impossible at the time it was first articulated. At present, Indiana University can justifiably claim leadership in this arena, as proposed by President Brand. This ambition persists today as part of 16th President Michael McRobbie's goal for Indiana University to be one of the great universities of the 21st century. After two decades, PTI has been successful beyond any expectations as laid out in 1999, and remains well positioned for continued success in the coming decades.

## 4. Acknowledgments

This document has benefitted from the intellectual contributions of many people involved in PTI past and present, including:

- Professor Dennis Gannon, the original Science Director of the Pervasive Technology Labs
- Professor Beth Plale, the most recent Science Director of the Pervasive Technology Institute, who developed many of the core concepts at the foundation of this document.
- Dr. D.F. "Rick" McMullen, who developed the first version of the "bubble diagram" in Figure 1-5.

[16] OmniSOC (https://omnisoc.iu.edu/) is a multi-institution Security Operations Center led by Indiana University. It currently provides integrated, automated security services to five major research universities.
[17] http://v4i.us/
[18] https://nsf.gov/pubs/2018/nsf18511/nsf18511.htm
[19] Dunn, J. Michael, & McRobbie, Michael. (1998). *Information technology strategic plan: architecture for the 21st century*. Indiana University. http://hdl.handle.net/2022/471

PTI has benefitted from many federal grants, as well as private grants and contracts. Major funding for PTI has come from the following sources:

| Fiscal Year Awarded | Project Title | PTI Center | Sponsor Name | Total Amount |
|---|---|---|---|---|
| 2005 | TeraGrid Resource Partners | RT | University of Illinois, Urbana-Champaign | $ 9,186,642 |
| 2010 | FutureGrid: An Experimental, High-Performance Grid Test-bed | DSC | NSF | $10,133,500 |
| 2012 | XSEDE: eXtreme Science and Engineering Discovery Environment | RT | University of Illinois, Urbana-Champaign | $6,315,115 |
| 2012 | THE OPEN SCIENCE GRID The Next Five Years: Distributed High Throughput Computing for the Nations Scientists, Researchers, Educators, and Students | RT | University of Wisconsin | $5,097,620 |
| 2013 | Center for Trustworthy Scientific Cyberinfrastructure | CACR | NSF | $4,518,845 |
| 2014 | High Performance Computing System Acquisition: Jetstream - a self-provisioned, scalable science and engineering cloud environment | RT | NSF | $9,974,683 |
| 2016 | CICI: Center of Excellence: Center for Trustworthy Scientific Cyberinfrastructure | CACR | NSF | $7,829,993 |
| 2017 | XSEDE 2.0 Extreme Science and Engineering Discovery Environment | RT | University of Illinois, Urbana-Champaign | $5,216,072 |
| 2018 | CICI: CSRC: Research SOC | CACR | NSF | $4,933,641 |
| | **Total** | | | $63,206,111 |

**Table 4-1 Major funding awards to PTI.**

## Appendix 1: PTI Timeline and Background

| Year | Event |
|---|---|
| 1999 | • Indiana Pervasive Computing Research Initiative (IPCRES) received $30M award from the Lilly Endowment. Dennis Gannon was appointed Science Director. |
| 1999-2005 | • The Pervasive Technology Labs, as PTI was then called, focused on recruiting top faculty talent to SICE (then, the School of Informatics) and expanding their research portfolios. |
| 2001 | • Andrew Lumsdaine was recruited to Indiana University as Associate Professor in School of Informatics, Associate Director of the Open Systems Lab, the first lab in PTL.<br>• Geoffrey C. Fox was recruited to Indiana University as Professor in School of Informatics, and Director of the Digital Science Center. |
| 2002 | • Pauline Baker was recruited to Indiana University as Professor in School of Informatics and Director of the VIS Lab.<br>• D.F. "Rick" McMullen, already a professional staff member at Indiana University, was appointed as Director of the Knowledge Acquisition and Projection Lab.<br>• Stephen Wallace, already a professional staff member at Indiana University, was appointed as Director of the Advanced Network Management Lab.<br>• Brian Voss was appointed Chief Operating Officer of PTL, as well as Associate Vice President of Telecommunications. |
| 2003 | • Randy Heiland was recruited to Indiana University as Associate Director of Scientific Data Analysis Lab (SDAL). |
| 2005 | • Craig Stewart became Chief Operating Officer of PTL and Associate Dean of Research Technologies. From the inception of PTL until 2005, PTL largely ignored the existence of what was then called the Research and Academic Computing Division of UITS. Leadership of PTL was ambiguous with a Chief Scientist, Dennis Gannon, and a COO, but with no CEO or director. |
| 2007 | • SDAL closed, due to lack of success in securing external funding. |
| 2008 | • With a second round of funding from the Lilly Endowment, PTL was restructured into the Pervasive Technology Institute, with Craig Stewart as Executive Director of PTI as well as Associate Dean for Research Technologies. PTI included three centers as of 2008:<br>  • The Digital Science Center evolved out of the lab previously run by Director Fox.<br>  • The Data to Insight Center was established as a center of PTI by elevating the lab run by Dr. Beth Plale to center status.<br>  • CACR became affiliated with PTI with Fred Cate as its Director. ANML was incorporated into CACR.<br>• The structure of PTI was expanded to include Research Technologies as one its "centers," and collaborations between Research Technologies and PTI research centers were pursued vigorously and encouraged.<br>• Dennis Gannon retired from Indiana University; Beth Plale was appointed as Science Director of PTI.<br>• PTI put new focus on fostering collaborations between faculty-led research centers (largely unsuccessfully), and on fostering collaborations between faculty-led PTI centers and the Research Technologies Division of UITS (largely successfully).<br>• KAPL closes due to loss of its major source of funding and resignation from Indiana University of Director D.F. Rick McMullen. |
| 2009 | • FutureGrid was awarded $10.1M from National Science Foundation to Indiana University with Geoffrey C. Fox as PI. This grant award created FutureGrid, a distributed testbed for grid and cloud computing, greatly aided by the Research Technologies Division of UITS. This remains one of just 6 federal awards to Indiana University, Bloomington since 1999 for a total amount in excess of $10M. |

| | |
|---|---|
| 2011 | • Thomas Sterling was recruited to Indiana University and the Center for Research in Extreme Scale Technologies was created, under the leadership of Director Andrew Lumsdaine and Associate Director and Chief Scientist Thomas Sterling.<br>• VIS (Visualization and Interactive Spaces) Lab closed as Director Pauline Baker prepares to retire from Indiana University. |
| 2008-2014 | • The majority (albeit not all) of the biggest and most intellectually important research done by PTI from 2008 to 2014 involved researchers depending on and leveraging cyberinfrastructure and services provided and supported by the Research Technologies Division of UITS. |
| 2014 | • The second award from the Lilly Endowment ended and the final report was published.<br>• The Center for Research in Extreme Scale Technologies (CREST) ended its collaborative relationships with PTI.<br>• Von Welch wass promoted to Director of CACR following Dr. Fred Cate's promotion to Indiana University VP for Research.<br>• Jetstream received an award totaling $12,388,710 (to date) from the National Science Foundation to Indiana University with Craig Stewart as PI. This award created the Jetstream cloud system now regarded as one of the most-liked cyberinfrastructure resources funded by the NSF. With this award, PTI became responsible for 2 of a total of 6 federal grant awards in excess of $10M to Indiana University, Bloomington from 1999 to today. |
| 2016 | • Thomas Sterling became Director of CREST (after Andrew Lumsdaine departed Indiana University). |
| 2017 | • Leadership of Research Technologies and PTI split into two positions, with Matt Link becoming the Associate Vice President for Research Technologies and Craig Stewart moving forward as Executive Director, Pervasive Technology Institute.<br>• CREST became re-affiliated with PTI.<br>• Data to Insight Center Director Beth Plale accepted IPA appointment at NSF; Inna Kouper named Interim Director of CACR. |
| 2018 | • CREST is disbanded in wake of the resignation of its director.<br>• PTI centers jointly fund a new editor within the Research Technologies Collaboration and Engagement Support Group to better support PTI competitiveness in pursuing grant awards.<br>• PTI adopts a shared governance model and center directors are given the title Associate Director, PTI.<br>• HTRC openly advertised as a standalone PTI center in wake of re-funding of HTRC by the HathiTrust/University of Michigan, with John Walsh (SICE/ILS) as director and PI. |

### *Centers formerly affiliated with PTI*

PTI is designed to be a resilient and persistent organization, which forms new centers as opportunities and needs arise. In a similar vein, the relative value of certain work changes over time, both for Indiana University and for federal (or other) funding agencies. So far, a total of five PTI-affiliated centers concluded their work and were closed:

- ANML (Advanced Network Management Lab)
- CREST (Center for Research in Extreme Scale Technologies)
- KAPL (Knowledge Acquisition and Projection Lab)
- SDAL (Scientific Data Analysis Lab)
- VIS (Visualization and Interactive Spaces)

### *Relationship to the Research Technologies Division*

PTI and Research Technologies are currently establishing distinct, but related, identities. Research Technologies is a Division of UITS that provides advanced cyberinfrastructure services and systems for use by the Indiana University community, engages in enhancing education and the economy of Indiana, executes federally funded grant awards, and is affiliated with PTI. PTI collaborates with and, in ways, depends on Research Technologies, but is more focused on externally-funded research. Research Technologies' mission is driven first by Indiana University's needs, and meets those needs through use of Indiana University general funds. Thus, Research Technologies is somewhat buffered from the vagaries of federal funding actions. PTI, exclusive of Research Technologies, receives a small amount of its total funding from Indiana University. For this reason, the centers other than Research Technologies are more heavily influenced by what the federal government will fund than on alignment with Indiana University's needs, capacity, and expertise. However, the two organizations are somewhat interdependent. For example, PTI is a source of grant monies flowing into Research Technologies, and the Research Technologies Collaboration and Engagement Support Group supports PTI in the preparation of grant proposals and in the execution of grant awards.

### *Relationship to OVPIT*

Factors contributing to PTI's close ties to OVPIT include the following:

- PTL and PTI began within OVPIT under the leadership of President McRobbie, who has issued strong directives regarding the importance of PTI's success. This history and OVPIT fidelity to priorities set by President McRobbie account for the persistence of these close ties.
- In times of scarce funding from the federal government for R&D, OVPIT has doubled down on its commitment to PTI while SICE has scaled back its direct involvement, primarily due to its own fiscal challenges.
- It makes sense in terms of Indiana University's strategies in computer science and cyberinfrastructure research, development, and delivery are based on the three-legged approach highlighted above.

PTI's close ties to OVPIT benefit OVPIT. The state authorization for creation of the CIB specified that the debt service on the building be paid from F&A monies, and delivering such monies to OVPIT is one of the outputs of PTI's effectiveness. In a more intellectually interesting way, there is a mutually beneficial interplay between PTI RD&D efforts and Research Technologies service delivery. The collaboration between the Research Technologies Division of UITS and the rest of PTI helps identify the line between "interesting enough to fund through research grants" and "things in which we should invest our money." Thus, both Indiana University's research and investments are made more effective.

## Appendix 2: PTI Influence: National Leadership, Awards, Honors

Through PTI, Indiana University influences local, state, and national high-technology ecosystems.

### *National Leadership*

**Conference Leadership**

- IEEE/ACM Supercomputing Conference Leadership
  - Matthew R. Link, AVP of Research Technologies and Associate Director of PTI, serves on the IEEE/ACM SCxy conference series most senior management committee, and is the only person from IU to ever be a member of this committee. Link has been involved in the IEEE/ACM Supercomputing Conference since 2003.
- IEEE Cloud Conference
  - Geoffrey C. Fox was the 2018 General Chair.
- IEEE Cluster Conference
  - Craig Stewart was the 2013 General Chair (https://pti.iu.edu/ieeecluster-2013/index.php).
- XSEDE
  - Craig Stewart was the XSEDE12 Conference General Chair, XSEDE 12 Conference
  - David Y. Hancock was named inaugural vice chair of the XSEDE Service Providers Forum in 2012.

**Congressional Testimony by PTI leaders**

- Current and past Center for Applied Cybersecurity Research directors have testified and spoken about cybersecurity repeatedly in Washington, D.C. and in many other venues.
- As Chair of the Coalition for Academic Scientific Computing (CASC), Craig Stewart testified before the House Science and Technology Committee about national high performance computing (HPC) strategies and has led a task force developing cyberinfrastructure strategies for the NSF.

**Federal Funding Agency engagement**

- Beth Plale, founding Director of the D2I Center and former Science Director of PTI is as of this writing on year 2 as a leading expert on data management and sharing; as such, she was recruited and hired by the NSF to lead policy and position development in this area for the CISE directorate.
- Craig Stewart worked part time for the NSF BIO directorate as an Expert from 2015-2016.
- Craig Stewart was a member of the NSF Advisory Committee for Cyberinfrastructure.
- Craig Stewart was Chair, NSF Advisory Committee for Cyberinfrastructure Task Force on Campus Bridging from 2009-2011.
- In the spring of 2018, PTI was represented by three individuals at an invitation-only workshop on the future of NSF funding for cyberinfrastructure. As far as we could tell, only one other institution was better represented than Indiana University via PTI.

**Federal agency engagement**

- Cooperative Research and Development Agreement (CRADA) between Naval Surface Warfare Center (NSWC) Crane and CACR, with an associated grant award. In 2016, CACR established a collaborative relationship with NSWC Crane on cybersecurity, instantiated by a Cooperative Research and Development Agreement (CRADA). This CRADA was renewed in September of 2018, and will bring $2M in funding to CACR. Indiana University now has a total of two CRADAs with Crane through CACR, accomplishing a largely unfulfilled objective of creating meaningful engagement between Crane and Indiana University.

**Non-profit advanced computing organizations**

- Coalition for Advanced Scientific Computation
  - Craig Stewart, Executive Director of PTI, was Chair of CASC from 2006-2008. As such, he has testified before the House Science and Technology Committee about national high performance

computing (HPC) strategies and has also led a task force developing cyberinfrastructure strategies for the NSF.
    - Stewart was elected secretary of CASC for 2019-2021
- Standard Performance Evaluation Corporation (SPEC)
    - Robert Henschel is the chair of the SPEC high-performance benchmarking group, one of the three leading groups in the world creating HPC benchmarks.

**Industry user groups**
- David Y. Hancock is the chair of the Cray User Group and has been past vice-chair of this group.
- David Y. Hancock was named vice president of the SPXXL user group (the IBM HPC user group) in 2010.
- Stephen Simms was a member of the Board of Directors of the Linux User Group.

**State Leadership**
- Indiana State Government
    - Voting cybersecurity
        - Von Welch

**Indiana University**
- Dr. Geoffrey C. Fox was the founding chairperson of the Department of Intelligent Systems Engineering in SICE.

*Awards*

**Best Papers**
- Phil Andrews Award for Most Transformative Contribution at PEARC18 (two recipients)
    - Ruan, G., Wernert, E., Gnaidy, T., Tuna, E., & Sherman, W. High Performance Photogrammetry for Academic Research. Paper presented at PEARC18, Pittsburgh, PA.
- Phil Andrews Best Technology Paper at PEARC17
    - Barth, B., Gaffney, N., Gaither, K., Hempel, C., Mehringer, S., Minyard, T., Panda, D.K., Stanzione, D., Teller, P., Tufo, H., & Wernert, E. Stampede 2: The Evolution of an XSEDE Supercomputer. Paper presented at PEARC17, New Orleans, LA.
- Phil Andrews Best Technical Paper Award, PEARC16
    - Stewart, C.A., Hancock, D.Y., Vaughn, M., Fischer, J., Cockerill, T., Liming, L., Merchant, N., Miller, T., Lowe, J.M., Stanzione, D.C., Taylor, J., Skidmore, E. (2016). Jetstream – performance, early experiences, and early results. In Proceedings of the 2016 XSEDE Conference: Diversity, Big Data & Science at Scale, doi:10.1145/2949550.2949639.
- Phil Andrews Best Technical Paper Award, PEARC15
    - Stewart, C.A., Roskies, R., Knepper, R., Moore, R.L., Whitt, J., & Cockerill, T.M. (2015). XSEDE Value Added, Cost Avoidance, and Return on Investment. In: Proceedings of the 2015 XSEDE Conference: Scientific Advancement Enabled by Enhanced Cyberinfrastructure, doi: http://dx.doi.org/10.1145.2792745.2792768.
- Best Technical Paper, SC10
    - Hoefler,T., T. Schneider, & A. Lumsdaine. (2010). Characterizing the Influence of System Noise on Large-Scale Applications by Simulation," pp. 1-11. In SC '10 Proceedings of the 2010 ACM/IEEE International Conference for High Performance Computing, Networking, Storage and Analysis

**Best Posters**
- Best Poster Award, PEARC18
    - Sarajlic, S., Chastang, J., Marru, S., Fischer, J., Lowe, M. (2018). Scaling JupyterHub Using Kubernetes on Jetstream Cloud: Platform as a Service for Research and Educational Initiativesin the Atmospheric Sciences. Poster presented at PEARC18, Pittsburgh, PA.

*Honors*

- Dr. Geoffrey C. Fox, Founding Director of the Digital Science Center, is the first (and this far only) person ever promoted to the rank of Distinguished Professor within the School of Informatics, Computing, and Engineering.
- Marlon Pierce and Suresh Marru are Apache Foundation Fellows.
- Craig Stewart, PTI Executive Director, was a Fulbright Senior Specialist visiting Technische Universitaet Dresden in 2006.

## Appendix 3: Comparison of PTI with similar organizations nationally

PTI is a peerless organization - not perhaps in the usual sense, but rather due to its unique organizational structure. Observations about similar organizations at other institutions include the following:

- The USC Information Sciences Institute (ISI) is a successful, software-oriented "soft money shop" focusing on computer science and cyberinfrastructure. Frequent Indiana University collaborator Ewa Deelman, leader of the Pegasus project, is at ISI. ISI, however, has a heavy administrative layer—12 individuals in its executive leadership team—and a Facilities and Administrative rate that has 65% as its floor, and goes up from there depending on the size of grant budgets.
- The National Center for Supercomputing Applications (NCSA) and the Texas Advanced Computing Center (TACC) are both more focused on the national research community than on their local communities. To the extent that they focus on local issues, they seem to exert a great deal of influence over the computer science departments at their respective institutions. The same is largely true of the San Diego Supercomputer Center (SDSC).
- The Pittsburgh Supercomputing Center is similar to NCSA and TACC in terms of national focus and is much less a multi-institution organization than it once was; in reality, today, PSC is an offshoot of Carnegie Mellon University. Furthermore, PSC, one of the original five NSF supercomputing centers, is now smaller than PTI in its aggregate size if one counts Research Technologies (Research Technologies) and the PTI centers as one.

While PTI is, indeed, without a precise peer, several smaller centers are using PTI as an example as they work to develop their own cyberinfrastructure centers. For instance, the Rutgers Discovery Informatics Institute (RDI2 - https://rdi2.rutgers.edu), the Ken Kennedy Institute for Information Technology (Rice University), and the IT center of the University of Wyoming are among several organizations being developed in line with PTI's example.

Some supercomputer/cyberinfrastructure centers PTI has overtaken in both size and renown since 1999 include the Cornell Theory Center/Center for Advanced Computing (one of the original five NSF supercomputing centers), the Ohio Supercomputing Center, the Minnesota Supercomputing Center, the Arctic Region Supercomputing Center, and the Wright Patterson AFB DOD HPC Center.

**Table A3-1: Comparison of Major Supercomputing Centers.**

| Center | Staff | Compute (PFLOPS) | Disk (PB) | Tape (PB) |
|---|---|---|---|---|
| ISI | 331 | - | - | - |
| SDSC | 330 | 3.1 | 15.3 | - |
| NCSA | 241 | 1.6 | 28 | 500 |
| TACC | 159 | 19+ | 39 | 160 |
| Argonne National Labs | 123 | 21.7 | 43.5 | 65 |
| **PTI** | **107** | **1.5** | **9.25** | **58** |
| PSC | 60 | 1.7 | 16 | - |
| Purdue | 56 | 0.9 | 9.1 | 10 |
| Minnesota Supercomputing Center | 46 | 0.9 | 4.9 | - |
| Ohio Supercomputing Center | 28 | 1.8 | 5 | 5.5 |

| | | | | |
|---|---|---|---|---|
| NICS | 22 | 0.2 | 1.7 | - |
| Notre Dame | 19 | < 1.0 | 3 | - |
| Cornell Center for Advanced Computing | 18 | - | - | - |
| University of Chicago | 17 | < 1.0 | 3.7 | - |

The information in Table A3-1 was compiled from public sources (with the exception of PTI) and may differ from internal accounting of staff and inventory at each center. Where performance data was not publicly available, it was estimated from the available information (e.g., nodes, cores, and CPU family). In some instances, no public information was available (empty entries). The information for PTI includes RT.