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Information systems enable rural development by increasing the accountability of nongovernmental organizations.

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Engineering Rural Development

ECONOMISTS AND ECOLOGISTS agree that the foremost challenge facing the world today is how to raise international standards of living while reducing humanity's environmental footprint. Also generally recognized is that the response must be global, including all human societies, cultures, and vocations. Nowhere is this more clearly articulated than in the Millennium Development Goals (www.un.org/millenniumgoals/), a mission statement for the world endorsed in 2000 by the 192 member states of the United Nations.

Access to information and communications technologies (ICTs) plays an increasingly important role in creating efficient markets and sustainable economic relationships. This is true not only for businesses but for initiatives in conservation, poverty reduction, and global health as well. To succeed, these efforts must be able to manage, understand, and react to globally distributed sources of information. Since the 1950s, advances in computing and other ICTs have revolutionized the way we create and share information, spurring an empirical revolution in fields as diverse and important as medicine, astronomy, biochemistry, economics, and ecology.

Understanding and responding to the global challenge of development must draw upon the same empirical and scientific methods. Failure to do so dooms us to repeat the same mistakes over and over. Computing technologies are essential for understanding the problems we face, as well as for planning, executing, and evaluating potential solutions. However, this process cannot be limited to the technical, social, and economic elite. To address historical disparities, it is essential that the poorest and least developed communities also contribute to, and benefit from, the global pool of knowledge.

Many rural ICT projects in developing countries have focused on individuals as the direct beneficiaries of technology. This includes efforts to improve rural education (such as the One Laptop Per Child project, laptop.org) and broader efforts to enable rural service delivery (such as the global movement to establish PC-based telecenters, or kiosks, www.telecentre.org). The early days of computing in the developed world emphasized business automation. Similarly, in rural areas of the developing world, one major initial benefit of ICTs will be the improvement, performance, and transparency of local institutions.

Nongovernmental organizations and community-based organizations, or NGOs and CBOs, can serve as an institutional basis for ICT adoption and use in the rural developing world. Due to their local knowledge and relationships, they are a key source of innovation, envisioning, implementing, and validating new models for rural

One farm inspector teaches another how to use Digital ICS in a village outside of Barillas, Guatemala, during an early field visit, spring 2006. (Photo by Ronak Parikh, now a student at Columbia University, then an intern at the University of Washington.)

development. Essentially, this is engineering, the process of generating, evaluating, and generalizing solutions to problems. Computing can play a critical role, enabling new and innovative solutions and better ways to demonstrate their contribution to human well being.

I start here with an overview of NGOs and CBOs and the value chain for recognizing and rewarding their work. To illustrate, I describe two information systems my students and I developed for improving NGO efficiency and accountability. I conclude by further describing the inherent engineering process within rural development and how computing can help enable it.

Civil Society

"Men are not birds," wrote Garrett Hardin, a professor of biology at the University of California, Santa Barbara, implying that for millennia humanity has abandoned the path of the animals (such as birds that would peck siblings to death when faced with the prospect of overpopulation[8]). The only civilized solution to the "tragedy of the commons," wrote Hardin, was "mutual coercion, mutually agreed upon by the majority of the people affected." Mutual coercion, or cooperation, is the basis for order in all human societies.

Civil society is an umbrella term for many kinds of voluntary and cooperative activities. Civil society organizations are nonprofit, non-state organizations representing people's social, economic, political, cultural, and environmental interests. In the developed world, they include charities, foundations, advocacy groups, and a variety of social service organizations. In the developing world, they are usually called NGOs, which, according to the World Bank, are characterized by their "voluntary and altruistic approach."[22]

NGOs focus on any number of issues, including educating children, empowering women, stemming rural migration, conserving the environment, and linking farmers to markets. They are characterized as operational or advocacy, depending on whether they "work in the field" designing and implementing specific development projects or influence policy and public opinion. Here, I use the term NGO to refer primarily to the operational NGOs working for socioeconomic development in rural areas of the developing world, including Latin America, South Asia, and Sub-Saharan Africa.

Where state and business infrastructure is limited or inaccessible, NGOs play a key role in organizing and supporting isolated communities, helping them access services like health care, education, training, and business development. By raising the standard of living and exposing people to new opportunities, NGOs are catalysts for change in rural areas throughout the developing world.

The World Bank classifies development NGOs into three categories: international, national, and commu-

Parikh explains to NGO field staff member how to use the Self-Help MIS mobile data-collection system while conducting usability studies in a village outside Madurai, Tamil Nadu, India, summer 2005. (University of California, Berkeley.)

nity-based, or CBOs.[22] International and national NGOs work through local offices, sometimes collaborating with smaller local NGOs and CBOs, to design, execute, and monitor development projects.

CBOs (also referred to as grassroots organizations) are distinct in that they are often membership-based and so directly represent a particular local community. Some CBOs also provide business services. For example, agricultural cooperatives allow small-holder farmers to achieve economies of scale in production, processing, marketing, and sales. Financial cooperatives (and smaller, informal entities, like mutual-liability microfinance groups) aggregate capital, conduct transactions, and distribute monitoring costs to enable convenient, affordable access to financial services. Larger NGOs are often catalysts in the formation, training, and capacity-building of CBOs.

NGOs function as change agents in rural areas by identifying promising opportunities for socio-economic development and then supporting communities to act on them. Where NGOs are not present, individuals and other concerned groups might play the same role. The inspiration for projects varies. Some are motivated by direct observation of a social or economic problem or opportunity. For example, the management of an NGO might be aware of a potential market for a local product (such as handicrafts or mangoes). By organizing the community to collect, process, and transport their products, it might be able to increase local income and employment. Other projects are based on replicating successful initiatives from elsewhere, learned through informal contact with funding agencies, other NGOs and/or explicit knowledge-sharing activities (such as workshops, publications, Web sites, and requests for proposals).

The strong network of NGOs and CBOs is associated with several positive externalities. The "social capital" accumulated within these groups, in the form of roles, norms, values, social networks, and opportunities for communication and sanction, has been found effective in making the groups more resistant to outside shocks, reliable in repaying loans, and efficient in conserving natural resources.[11,17,20]

In theory, the vetting and monitoring process should be similar to what takes place in the corporate world where investors and prospective shareholders regularly assess the financial performance of companies.

Civil Society Value Chain

The value chain that rewards NGOs for positive results is still evolving. For many smaller NGOs and those CBOs that do not engage in economic activity, the primary source of funding is private donations or grants from foundations and government agencies. Some work closely with national or regional governments. The majority rely on foundations, charities, and international NGOs that themselves raise money from governments, donors, and larger institutional sources and then grant (or subcontract) to smaller local NGOs. To establish and maintain funding relationships, NGOs must demonstrate positive social and economic outcomes and the potential for broader impact arising from their work.

Recently, CBOs have had more market-based opportunities for leveraging their social, economic, and environmental impacts. Here are a few examples:

Organic certification. Organic certification provides producer cooperatives a price premium for practicing healthier and more environmentally sustainable growing practices;

Fair trade. Fair-trade certification provides producer cooperatives a price premium to promote better compensation for farmers;

Microfinance. Microfinance groups receive preferential access to capital based on their social impact as measured by various indicators; and

Environmental services. Farmers receive payment for providing environmental services (such as retaining native trees and maintaining soil nutrients) to the global community.

To institute a fair reward system, these mechanisms require a compelling and verifiable demonstration of benefit, but the tools available to NGOs for doing so are limited. Their information systems, even when automated, are often based on manual data collection and entry, locally developed data management and reporting software, and limited IT infrastructure and expertise. In these scenarios, the quality, quantity, and timeliness of data might all be lacking. Outside the rapidly commercializing world of microfinance, NGO systems are rarely audited by donors, governments, or other agencies.

As a result, prospective funders find it difficult to assess the quality of their

work. Dedicated and effective grassroots organizations have trouble differentiating themselves from superficial, media-savvy operations. Fraud and corruption abound, including sham projects receiving prestigious awards and multimillion-dollar grants.[2] In theory, the vetting and monitoring process should be similar to what takes place in the corporate world, where investors and prospective shareholders regularly assess the financial performance of companies. Even this highly resourced and regulated relationship has experienced notable failures of oversight. For social investing, ensuring due diligence is made even more difficult by limited NGO resources and capacity and by the fact that there are many different ways of defining, measuring, and demonstrating impact.

The vision and mission of any given NGO usually emanates from its leadership, often dedicated professionals with strong ties to the community. Many NGOs face significant constraints in terms of technical expertise and management capacity, particularly beyond that leadership. Still, no matter how charismatic the head man or woman might be, the field staff is the glue that binds the NGO to the community. Field staff members are recruited from villages and have a thorough understanding of the local culture and context. This is not to say their jobs are easy, anything but. Field staff must travel from village to village using unreliable public transportation or walking, even as they build and maintain relationships with local residents.

NGOs are usually organized around a specific development purpose and infused with optimism, idealism, and institutional legitimacy, making them effective change agents. On the other hand, local people may be struggling just to make ends meet. One of the field staff's many tasks is to translate the organization's mission into community terms and encourage its participation. Fostering strong communication with the community is essential for ensuring that projects make progress and address real needs.

System Requirements

The basic requirements for NGO information systems are similar to those for other organizations. Field staff members collect data using paper forms and PCs or other computing devices. This data is aggregated in a database or manual paper file. From there, it is processed by either a computer or human to generate reports useful for communicating with management, staff, beneficiaries, outside parties, and funding sources. To fulfill their objectives, NGOs must address a number of information and communication needs:

Operations. They must coordinate the operations associated with their activities. As an example, for an agricultural cooperative, quality control, procurement, processing, and delivery must all be part of their systems and processes. For those NGOs working in microfinance, loan payments must be collected, documented, and deposited in a bank. Even if a CBO is nominally in charge of these processes, unless it has sufficient scale and capacity, it often needs the assistance of a supporting NGO and its field staff;

Training and monitoring staff. NGO field staff members operate in far-flung areas with limited supervision from management. They often assist and even manage CBO operations. They are the source of feedback from the community, including problems, needs, and results of ongoing efforts. Field staff must be trained to execute these responsibilities and monitored to ensure they do not cheat, shirk, or introduce bias. Given their low pay and limited training, the difficulty of traveling in rural areas, and opportunities to leverage their NGO affiliation, this is not easily done. However, technologies as simple as a digital camera have been found effective for ensuring accountability[5];

Documenting results. Most staff data-collection activity is for documenting the results of NGO activities. The data could be used for internal monitoring and learning but is more often motivated by the reporting demands of funders. Traditionally, the funders request quantitative indicators (such as increased income, loan repayment rate, or number of people treated or vaccinated). Because these indicators favor preordained and externally determined metrics of success, more community-driven ways of measuring results have also been developed. One such method asks beneficiaries to report the "most significant change" associated with an

Technologies as simple as a digital camera have been found effective for ensuring accountability.

Coffee producers of Aldea Cocolá Grande, Barillas, Guatemala. (Photo by Baltazar Francisco Miguel, general manager of ASOBAGRI, an organic coffee cooperative in Barillas, Guatemala.)

intervention through qualitative interviews and participatory video tapings (www.mande.co.uk/MSC.htm);

Accounting. NGOs must show how they've allocated expenses to specific projects for reporting to funders. As many smaller NGOs lack funding for their infrastructure and core operations, managing this overhead requires finding ways to account for these expenses through funded projects. Most mid-to-large-size NGOs use some kind of commercial accounting software to manage their books. Most registered entities also seek the services of certified accountants. Specific country regulations for nonprofits (such as for filing taxes and/or documenting foreign donations) must be followed;

Reporting. Impact and budget data must be reported regularly to donors, governments, and/or regulatory agencies. Each usually insists on using its own reporting formats and indicators. NGO information systems, from data collection to reporting, are driven by these requirements and built and modified as they arise, with little upfront planning or dedicated design effort. The result is a hodge-podge of code and data that is impossible to maintain—and ultimately might not be secure or usable;

Decision making and learning. The focus on external reporting leaves little room for internal decision making and learning. Many NGOs do not employ a systematic effort to collect data useful for understanding the real effect of their programs. As a result, many NGO managers run their organizations through personal intuition and by following trends, informed by whatever knowledge reaches them through their organization's ad hoc communication channels. Only large professional NGOs or those associated with international networks that are able to leverage significant economies of scale have custom-built information systems designed to meet their own requirements; even these usually meet only the needs of NGO headquarters, not those of their regional or field offices;

External knowledge. NGOs serve as a gateway for accessing external information useful to CBOs and rural communities. For agricultural cooperatives, this might include weather forecasts, reviews of new seed varieties, and descriptions of new farming practices and technologies. NGO management and staff must filter, adapt, and/or translate it so it is relevant for and understandable by the community. Ideally, the community should be able to contribute its knowledge as well; it, too, must be filtered, adapted, and/or translated by the NGO to tailor it to a broader audience; and

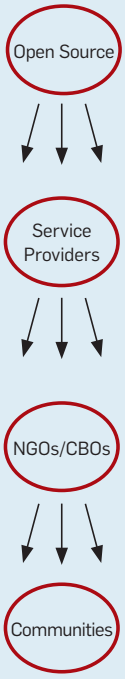
Community participation. The most basic operational task for NGOs and CBOs is maintaining consistent bidirectional communication with community members and is especially important for the governance of membership-based organizations like cooperatives. While field staff members are rewarded for spreading the NGO's message and collecting data required by funders, there is little incentive for them to report unsolicited feedback from the field. As a result, many NGO managers have only a limited understanding of local problems and the status of their own organization's field efforts. Rich information dissemination and feedback tools could help NGOs be more accountable to their communities and encourage greater community participation.

Promising Approaches

Rural NGO and CBO information and communications needs (see Figure 1) are supported by a number of promising technology developments:

Mobile phones. The decreasing cost and improving capabilities of mobile

Figure 1: Information services ecology for rural communities. Open source software enables technology service providers to support NGOs and CBOs that provide relevant and accessible information services to local communities.



phones make them a compelling computing platform, especially for mobile field staff. Beyond voice and text communications, they might also be used for data collection, decision support, and knowledge dissemination, including the capture and playback of multimedia. My students and I have implemented mobile applications in India, Mexico, and Tanzania for documenting microfinance transactions,[13] inspecting organic coffee farms,[18] and diagnosing and treating childhood illnesses.[3] One constraint we continue to face is the lack of open, accessible, cross-platform mobile development tools;

Open source. Implementing business software requires extensive customization, training, and maintenance. Providing these services is the basis for successful service business models for such companies as IBM, Oracle, and SAP. However, it would be incredibly difficult for a centralized organization to provide these services to remote locations across a large geographic area.[12] Local service providers, operating in capitals and regional hubs, are essential to the NGO information services ecology. Open source software could provide a foundation upon which other providers could build customized applications and/or provide value-added services;

Cloud computing. Due to the challenge of installing and maintaining software in remote locations, a software-as-service approach might also be useful.[7] Software in the cloud would be easier to install, maintain, and update. However, in the rural developing world, the lack of access to reliable broadband connectivity limits uptake of this model. Improving the quality and availability of high-bandwidth network connections could alleviate this limitation; so would providing a mechanism for offline access. Even so, localization and other customizations require an open and flexible software architecture;

Store-and-forward networking. Due to spotty network coverage, asynchronous networking technologies to provide offline access to services are useful for PC-based and especially for mobile clients. This requires methods for intelligent caching and transfer of data. Given that NGO staff members regularly visit both field and head offices, these offices can serve as asynchronous communications hubs for rural communities. Highly decentralized projects in remote regions with low population density and limited infrastructure, and where field staff may stay in the field weeks at a time, could benefit from multihop networking approaches[4];

Long-distance wireless. For applications requiring synchronous communications (such as telemedicine and voice telephony), the decreasing cost of long-distance, high-bandwidth wireless connections is a promising development.[15] They represent a compelling tool for linking remote NGO offices with human and information resources that are likely available only in cities and other centralized locations;

Narrowcast media. The declining cost of media production, dissemination, and playback over the next decade promises to revolutionize how NGOs disseminate information. Community radio is a powerful yet low-cost tool for broadcasting audio content in a specific geographic area. Using video cameras and DVD players to generate and distribute media content has been found beneficial for activities as diverse as children's education and agricultural extension.[6, 21] How to enable communities to generate their own content or provide feedback to content producers is an important and largely ignored challenge.

Many NGO managers run their organizations through personal intuition and by following trends, informed by whatever knowledge reaches them through their organization's ad hoc communication channels.

Bootstrapping a Service Ecology

Implementing computing applications for rural NGOs requires building local capacity for software development, integration, customization, installation, training, maintenance, and support. In most developing countries, the IT services sector, if there is one, focuses on outsourcing and building commercial applications. NGOs usually rely on second- and third-tier programming talent. For large development projects, the only alternative is to hire expensive foreign consultants or companies from established IT markets and fly them in and out as needed. For many NGOs this is not feasible financially or logistically. As a result, most applications intended for NGOs are being developed by poorly trained local programmers using a limited set of tools.

Several approaches are required to address this problem. Foremost is the emergence of a robust IT services in-

dustry in more countries. Working in Africa and India, I have personally met many talented developers and small software companies committed to working with NGOs. More opportunities and resources must be provided by governments and funding agencies to encourage them to serve the nonprofit sector. This could help bootstrap IT service businesses in countries with limited access to outside markets. Enabling these relationships requires a better social network connecting NGOs, software-training institutes, fledgling software companies, and funding sources, including (social) venture capital.

Better software-development tools would also help, particularly for mobile applications. Microsoft's .NET framework is a well-integrated, well-documented, full-featured proprietary development platform for which there is significant infrastructure worldwide for developer training and support. However, many NGOs are unwilling to pay license fees for software and uncomfortable using pirated software and may oppose being tied to a particular operating system. As a result, there is a notable push by NGOs toward open source. For mobile applications, more openness and standardization are sorely needed, as is better support for cross-platform development. Recent efforts by Apple, Google, and Nokia to provide more open development platforms seem to be a step in the right direction.

In terms of application software, neither the shrink-wrap nor the proprietary-software-plus-services model has worked for rural NGOs.[12] Providing a suite of useful open source applications could be an effective alternative, potentially having a cascading positive effect on local economic development. Each open source application could create a number of opportunities for local IT companies to serve NGOs, each in turn serving a number of local communities and individuals. This is the kind of public good that governments and donors should provide.

Several open source applications have been developed for NGOs, including for managing microfinance programs (www.mifos.org) and maintaining electronic health records (www.openmrs.org). This trend allows local software providers to focus on adding value, including customization, localization, installation, maintenance, and support. Improvements and additions to the code can later be fed back to the main branch, lowering the barrier to entry for future implementers. Working on such globally distributed projects requires effective collaboration-and-governance tools that work across time zones and cultures.

Finally, the global research and development community must address the challenges of computing in the rural developing world, one of the last frontiers of computing adoption. Researchers working in this field have already provided novel insights into shared computing, interfaces for semiliterate users, and long-distance networking technologies for reaching remote locations.[14, 15, 16]

Working Systems

To illustrate these concepts, I describe two systems—Self-Help MIS and Digital ICS—my students and I built in collaboration with rural NGOs and CBOs. These systems demonstrate how information technology is being used to automate existing processes and provide new opportunities for development. While a formal long-term evaluation is pending, initial results have been positive and generated additional demand from other civil society organizations. (For more, please see [13, 18]).

Self-Help MIS. Self-help groups, or SHGs, are semi-independent microfinance groups located throughout rural and peri-urban India. They usually consist of 15 to 20 members, mostly women (see Figure 2). Group members save money during regular group meetings, rotating the accumulated capital in the form of loans that are repaid with interest, increasing the group's corpus. When the total amount becomes too much for the SHG to manage, it is disbursed back to the group members. The cycle then starts again, sometimes with the reshuffling of members among groups. SHGs are promoted by NGOs, banks, farmer groups, individuals, and government agencies in India. Beside the immediate benefit of providing access to financial services, SHGs are also a mechanism for organizing other community development activities.

Working with SHGs is attractive for local banks, as they lessen the need to build physical branch offices in remote areas and thereby reduce the cost of providing financial services. However, banks often have no way to address SHG quality and history, making it difficult to determine the risks associated with various products and services (such as the lending of money). Due to limited literacy and education, many SHGs keep inconsistent and/or incomplete records. Many need the help of literate people, sometimes the field staff of a local NGO, to maintain their records

Figure 2: Field staff capturing data from a self-help-group meeting.

and prepare reports for internal oversight and external assessment. Lack of transparency and internal controls can also lead to problems within an SHG, including the capture of assets by elite members by stealing and/or taking a disproportionate share of loans.

In collaboration with ekgaon technologies (or "one village" in Hindi, www.ekgaon.com), a technology firm I cofounded in 2002 in India, and the Covenant Centre for Development (www.ccd.org.in), an SHG-promoting NGO in Tamil Nadu, India, I developed Self-Help MIS, a system for monitoring a network of SHGs. Group members record transaction data using paper forms that are processed by field staff using a mobile phone to capture and upload data to a database application running at the NGO office. When field staff visit again, they print reports to take back to the SHG, which uses them in its next meeting and as supporting documentation when applying to a bank for a loan. NGO management can also use this data to monitor SHG performance, addressing potential trouble spots and demonstrating the outreach and impact of the SHG program to their funders. If new services or products are introduced, NGO management can empirically determine their uptake and impact.

Deployed since October 2006, Self-Help MIS is being used by more than 1,000 SHGs and their 15,000 members. Ekgaon has negotiated a service contract to translate the system into six languages (besides the original Tamil) and deploy the system in several additional states. As one of the first SHG information systems to provide intra-group transparency through direct field-level data collection, one World Bank project is using it as a model for learning how to establish a network of SHG credit reporting bureaus, with a potential total outreach of millions of group members.

Digital ICS. My students and I are working with two farmer cooperatives in Mexico and Guatemala that produce certified organic and shade-grown coffee (without chemicals while retaining native trees on coffee parcels). Maintaining these certifications requires arduous paperwork and diligent internal oversight. In both cooperatives, they are inspected every one to three years by various certifying agencies. External inspectors visit a randomly selected cross-section of farm plots and processing equipment. If they observe inconsistencies, the cooperative's certification (and price premium) might be at stake.

To avoid this risk, cooperatives institute stringent internal controls. Twice a year, local inspectors, selected from the ranks of field staff, office staff, and trusted farmers, visit every coffee parcel belonging to each cooperative's members. This inspection requires completing and delivering a lengthy form to the cooperative's internal control manager. The manager reviews the inspection data, singling out farmers having problems with the transition to organic chemical-free production or at risk of violating certification requirements. On their next visit, field staff convey advice, reprimands, and/or sanctions to farmers on behalf of the manager.

To automate this process, my students and I implemented the Digital Internal Control System (or DigitalICS, pronounced *digitalix*). Inspectors fill out forms directly on Nokia 6600 mobile phones, collecting pictures of farm plots and equipment and audio recordings of farmers' explanations, questions, and comments that are useful as evidence of breaches of certification requirements, for resolving disputes, and for targeting agricultural training and extension activities. As evidence of their visits, the cooperative requires that each inspector photograph the farmers on their plots (see Figure 3). This is intended to ensure that staff visit and document every parcel, not easily done when some take hours to reach and are on steep inclines miles from the nearest road. On the next visit to the cooperative office, inspection data is uploaded to a Web-based database application we developed. The internal control manager reviews inspection forms through this application, automatically generating reports for certifying agencies. The manager also enters feedback and notes for later discussion with field staff and for conveying back to the farmers.

The same technology and process can be used to provide traceability, grading, collecting feedback from farmers, monitoring social and economic impact, and instituting reward mechanisms tied directly to farm-level quality. Digital ICS is one of the first systems to provide these features in an integrated manner by allowing for the collection of rich multimedia data through mobile phones. Digital ICS has been through two trials conducted with the Coffee Grows Association of Oaxaca, Mexico (CEPCO), where it is being used by more than 1,000 farmers as part of their regular operations. In the future, CEPCO and Asobagri (our partner in Guatemala) would like to use the system to also produce better marketing materials and facilitate more communication between producers and consumers. Another idea is to monitor the environmental services provided by coffee farmers, including retaining native trees and/or planting new ones. After being verified by a third-party process similar to certification, these services can be sold as credits on the international carbon market.

Figure 3: Photo used as evidence that field staff visited a particular farm parcel.

Development as Engineering

Grace Hopper, a computing pioneer in the U.S. Navy, wrote that the role of computers is "freeing mathematicians to do mathematics."[9] The focus of today's efforts to develop information systems that support rural development is similar: free development practitioners to do development. Development economists have largely given up on theory-driven models, increasingly recognizing that there is no single magic elixir for development; solutions to specific problems must be conceived, implemented, rigorously evaluated, replicated, and scaled.[1] The development process has become more incremental and empirical, like engineering, the process of identifying, validating, and generalizing solutions to problems.

Herbert Simon, a professor at Carnegie Mellon University, described design and engineering as the "sciences of the artificial."[19] Unlike the natural

sciences, which are concerned with how things are, these fields are concerned with how things should be. The goal of an engineer is to build systems that achieve some desired result, based on a process that centers on the generate-test cycle, producing likely solutions and testing whether they are successful relative to some desired metric. How to design in anticipation of a positive result and evaluate whether or not that result is as anticipated are the methodological and empirical bases for this trade.

From this perspective, ICTs should not be viewed as a panacea for development but as a tool allowing local change agents (like NGOs) to be more effective and accountable. As the examples here show, computing is able to support local organizations in generating and sharing new ideas, implementing and disseminating projects, and measuring their effects. The goal is to facilitate a virtuous cycle of experimentation by augmenting local efforts and improving their visibility and accountability to the institutions that might support, replicate, scale and/or learn from them.

Here, I have highlighted the role of NGOs, but one could equally focus on government agencies and local businesses. NGOs are important sources of innovation for rural development. Their familiarity with the problems and people of a region, along with their idealism and activism, enable them to identify and pursue novel development strategies. Their lack of government and commercial accountability allows them to be more creative and free in this enterprise. If an idea is demonstrably successful, it can later be scaled through state or business approaches.

Conclusion

How can computer scientists and engineers design computing technologies to achieve desired development objectives? Mobile phones have demonstrated a positive contribution, improving the efficiency of commodity markets in a variety of contexts.[10] While the simple ability to communicate provides an immediate advantage, the effect of computing often takes time to realize. Specifically, it must be accompanied by organizational and procedural changes that take advantage of the new opportunities computing affords (such as decision making based on analysis of past performance).

Many technologies useful for achieving these goals are technologically simple. Complexity arises in their adoption and interaction with human social and organizational systems. To manage this complexity, computer scientists and engineers must improve the process of designing, introducing, and evaluating computing technologies. This engineering process involves understanding local users, designing appropriate and easy-to-introduce solutions, and demonstrating their ability to achieve beneficial social and economic change. This process must also be contextual and iterative, requiring rich learning from field tests and pilot deployment of varying scale and duration.

Approaching these issues rigorously should require methods from the social sciences, including user studies and ethnography used for decades to study human-computer interaction. The emphasis on process must now go beyond user interface design to encompass end-to-end application and systems design. Students of computing must not only learn the mechanics of computing and its underlying abstractions and analytic foundations but also the how to design and evaluate computing systems that achieve specific human objectives.

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