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3.2. Measure Twice, Cut Once: Cooperative Deployment of a Generalized, Archaeology-Specific Field Data Collection System

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Adela Sobotkova, Shawn A. Ross, Brian Ballsun-Stanton, Andrew Fairbairn, Jessica Thompson, and Parker VanValkenburgh

MOBILIZING *the* PAST *for a* DIGITAL FUTURE

The Potential of
Digital Archaeology



Edited by
Erin Walcek Averett
Jody Michael Gordon
Derek B. Counts

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FOR A
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The Digital Press @
The University of North Dakota
Grand Forks

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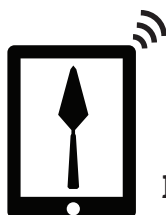
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Preface & Acknowledgments

This volume stems from the workshop, “Mobilizing the Past for a Digital Future: the Future of Digital Archaeology,” funded by a National Endowment for the Humanities Digital Humanities Start-Up grant (#HD-51851-14), which took place 27-28 February 2015 at Wentworth Institute of Technology in Boston (<http://uwm.edu/mobilizing-the-past/>). The workshop, organized by this volume’s editors, was largely spurred by our own attempts with developing a digital archaeological workflow using mobile tablet computers on the Athienou Archaeological Project (<http://aap.toumazou.org>; Gordon *et al.*, Ch. 1.4) and our concern for what the future of a mobile and digital archaeology might be. Our initial experiments were exciting, challenging, and rewarding; yet, we were also frustrated by the lack of intra-disciplinary discourse between projects utilizing digital approaches to facilitate archaeological data recording and processing.

Based on our experiences, we decided to initiate a dialogue that could inform our own work and be of use to other projects struggling with similar challenges. Hence, the “Mobilizing the Past” workshop concept was born and a range of digital archaeologists, working in private and academic settings in both Old World and New World archaeology, were invited to participate. In addition, a livestream of the workshop allowed the active participation on Twitter from over 21 countries, including 31 US states (@MobileArc15, #MobileArc).¹

¹ For commentary produced by the social media followers for this event, see: <https://twitter.com/electricarchaeo/status/571866193667047424>, <http://shawngraham.github.io/exercise/mobilearcday1wordcloud.html>, <https://twitter.com/electricarchaeo/status/571867092091338752>, <http://www.diachronicdesign.com/blog/2015/02/28/15-mobilizing-the-past-for-the-digital-future-conference-day-1-roundup/>.

Although the workshop was initially aimed at processes of archaeological data recording in the field, it soon became clear that these practices were entangled with larger digital archaeological systems and even socio-economic and ethical concerns. Thus, the final workshop's discursive purview expanded beyond the use of mobile devices in the field to embrace a range of issues currently affecting digital archaeology, which we define as the use of computerized, and especially internet-compatible and portable, tools and systems aimed at facilitating the documentation and interpretation of material culture as well as its publication and dissemination. In total, the workshop included 21 presentations organized into five sessions (see program, <http://mobilizingthepast.mukurtu.net/digital-heritage/mobilizing-past-conference-program>), including a keynote lecture by John Wallrodt on the state of the field, "Why paperless?: Digital Technology and Archaeology," and a plenary lecture by Bernard Frischer, "The Ara Pacis and Montecitorio Obelisk of Augustus: A Simpirical Investigation," which explored how digital data can be transformed into virtual archaeological landscapes.

The session themes were specifically devised to explore how archaeological data was digitally collected, processed, and analyzed as it moved from the trench to the lab to the digital repository. The first session, "App/Database Development and Use for Mobile Computing in Archaeology," included papers primarily focused on software for field recording and spatial visualization. The second session, "Mobile Computing in the Field," assembled a range of presenters whose projects had actively utilized mobile computing devices (such as Apple iPads) for archaeological data recording and was concerned with shedding light on their utility within a range of fieldwork situations. The third session, "Systems for Archaeological Data Management," offered presentations on several types of archaeological workflows that marshal born-digital data from the field to publication, including fully bespoke paperless systems, do-it-yourself ("DIY") paperless systems, and hybrid digital-paper systems. The fourth and final session, "Pedagogy, Data Curation, and Reflection," mainly dealt with teaching digital methodologies and the use of digital repositories and linked open data to enhance field research. This session's final paper, William Caraher's "Toward a Slow Archaeology," however, noted digital archaeology's successes in terms of

time and money saved and the collection of more data, but also called for a more measured consideration of the significant changes that these technologies are having on how archaeologists engage with and interpret archaeological materials.

The workshop's overarching goal was to bring together leading practitioners of digital archaeology in order to discuss the use, creation, and implementation of mobile and digital, or so-called "paperless," archaeological data recording systems. Originally, we hoped to come up with a range of best practices for mobile computing in the field – a manual of sorts – that could be used by newer projects interested in experimenting with digital methods, or even by established projects hoping to revise their digital workflows in order to increase their efficiency or, alternatively, reflect on their utility and ethical implications. Yet, what the workshop ultimately proved is that there are many ways to "do" digital archaeology, and that archaeology as a discipline is engaged in a process of discovering what digital archaeology should (and, perhaps, should not) be as we progress towards a future where all archaeologists, whether they like it or not, must engage with what Steven Ellis has called the "digital filter."

So, (un)fortunately, this volume is not a "how-to" manual. In the end, there seems to be no uniform way to "mobilize the past." Instead, this volume reprises the workshop's presentations—now revised and enriched based on the meeting's debates as well as the editorial and peer review processes—in order to provide archaeologists with an extremely rich, diverse, and reflexive overview of the process of defining what digital archaeology is and what it can and should perhaps be. It also provides two erudite response papers that together form a didactic manifesto aimed at outlining a possible future for digital archaeology that is critical, diverse, data-rich, efficient, open, and most importantly, ethical. If this volume, which we offer both expeditiously and freely, helps make this ethos a reality, we foresee a bright future for mobilizing the past.

* * *

No multifaceted academic endeavor like *Mobilizing the Past* can be realized without the support of a range of institutions and individ-

uals who believe in the organizers' plans and goals. Thus, we would like to thank the following institutions and individuals for their logistical, financial, and academic support in making both the workshop and this volume a reality. First and foremost, we extend our gratitude toward The National Endowment for the Humanities (NEH) for providing us with a Digital Humanities Start-Up Grant (#HD-51851-14), and especially to Jennifer Serventi and Perry Collins for their invaluable assistance through the application process and beyond. Without the financial support from this grant the workshop and this publication would not have been possible. We would also like to thank Susan Alcock (Special Counsel for Institutional Outreach and Engagement, University of Michigan) for supporting our grant application and workshop.

The workshop was graciously hosted by Wentworth Institute of Technology (Boston, MA). For help with hosting we would like to thank in particular Zorica Pantić (President), Russell Pinizzotto (Provost), Charlene Roy (Director of Business Services), Patrick Hafford (Dean, College of Arts and Sciences), Ronald Bernier (Chair, Humanities and Social Sciences), Charles Wiseman (Chair, Computer Science and Networking), Tristan Cary (Manager of User Services, Media Services), and Claudio Santiago (Utility Coordinator, Physical Plant).

Invaluable financial and logistical support was also generously provided by the Department of Fine and Performing Arts and Sponsored Programs Administration at Creighton University (Omaha, NE). In particular, we are grateful to Fred Hanna (Chair, Fine and Performing Arts) and J. Buresh (Program Manager, Fine and Performing Arts), and to Beth Herr (Director, Sponsored Programs Administration) and Barbara Bittner (Senior Communications Management, Sponsored Programs Administration) for assistance managing the NEH grant and more. Additional support was provided by The University of Wisconsin-Milwaukee; in particular, David Clark (Associate Dean, College of Letters and Science), and Kate Negri (Academic Department Assistant, Department of Art History). Further support was provided by Davidson College and, most importantly, we express our gratitude to Michael K. Toumazou (Director, Athienou Archaeological Project) for believing in and supporting our

research and for allowing us to integrate mobile devices and digital workflows in the field.

The workshop itself benefitted from the help of Kathryn Grossman (Massachusetts Institute of Technology) and Tate Paulette (Brown University) for on-site registration and much more. Special thanks goes to Daniel Coslett (University of Washington) for graphic design work for both the workshop materials and this volume. We would also like to thank Scott Moore (Indiana University of Pennsylvania) for managing our workshop social media presence and his support throughout this project from workshop to publication.

This publication was a pleasure to edit, thanks in no small part to Bill Caraher (Director and Publisher, The Digital Press at the University of North Dakota), who provided us with an outstanding collaborative publishing experience. We would also like to thank Jennifer Sacher (Managing Editor, INSTAP Academic Press) for her conscientious copyediting and Brandon Olson for his careful reading of the final proofs. Moreover, we sincerely appreciate the efforts of this volume's anonymous reviewers, who provided detailed, thought-provoking, and timely feedback on the papers; their insights greatly improved this publication. We are also grateful to Michael Ashley and his team at the Center for Digital Archaeology for their help setting up the accompanying Mobilizing the Past Mukurtu site and Kristin M. Woodward of the University of Wisconsin-Milwaukee Libraries for assistance with publishing and archiving this project through UWM Digital Commons. In addition, we are grateful to the volume's two respondents, Morag Kersel (DePaul University) and Adam Rabinowitz (University of Texas at Austin), who generated erudite responses to the chapters in the volume. Last but not least, we owe our gratitude to all of the presenters who attended the workshop in Boston, our audience from the Boston area, and our colleagues on Twitter (and most notably, Shawn Graham of Carlton University for his word clouds) who keenly "tuned in" via the workshop's livestream. Finally, we extend our warmest thanks to the contributors of this volume for their excellent and timely chapters. This volume, of course, would not have been possible without such excellent papers.

As this list of collaborators demonstrates, the discipline of archaeology and its digital future remains a vital area of interest for people who value the past's ability to inform the present, and who

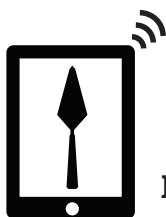
recognize our ethical responsibility to consider technology's role in contemporary society. For our part, we hope that the experiences and issues presented in this volume help to shape new intra-disciplinary and critical ways of mobilizing the past so that human knowledge can continue to develop ethically at the intersection of archaeology and technology.

Erin Walcek Averett (Department of Fine and Performing Arts and Classical and Near Eastern Studies, Creighton University)

Jody Michael Gordon (Department of Humanities and Social Sciences, Wentworth Institute of Technology)

Derek B. Counts (Department of Art History, University of Wisconsin-Milwaukee)

October 1, 2016



How To Use This Book

The Digital Press at the University of North Dakota is a collaborative press and *Mobilizing the Past for a Digital Future* is an open, collaborative project. The synergistic nature of this project manifests itself in the two links that appear in a box at the end of every chapter.

The first link directs the reader to a site dedicated to the book, which is powered and hosted by the Center for Digital Archaeology's (CoDA) Mukurtu.net. The Murkutu application was designed to help indigenous communities share and manage their cultural heritage, but we have adapted it to share the digital heritage produced at the "Mobilizing the Past" workshop and during the course of making this book. Michael Ashley, the Director of Technology at CoDA, participated in the "Mobilizing the Past" workshop and facilitated our collaboration. The Mukurtu.net site (<https://mobilizingthepast.mukurtu.net>) has space dedicated to every chapter that includes a PDF of the chapter, a video of the paper presented at the workshop, and any supplemental material supplied by the authors. The QR code in the box directs readers to the same space and is designed to streamline the digital integration of the paper book.

The second link in the box provides open access to the individual chapter archived within University of Wisconsin-Milwaukee's installation of Digital Commons, where the entire volume can also be downloaded. Kristin M. Woodward (UWM Libraries) facilitated the creation of these pages and ensured that the book and individual chapters included proper metadata.

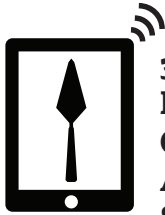
Our hope is that these collaborations, in addition to the open license under which this book is published, expose the book to a wider audience and provide a platform that ensures the continued availability of the digital complements and supplements to the text. Partnerships with CoDA and the University of Wisconsin-Milwaukee reflect the collaborative spirit of The Digital Press, this project, and digital archaeology in general.

Abbreviations

AAI	Alexandria Archive Institute
AAP	Athienou Archaeological Project
ABS	acrylonitrile butadiene styrene (plastic)
ADS	Archaeological Data Service
Alt-Acs	Alternative Academics
API	application programming interface
ARA	archaeological resource assessment
ARC	Australian Research Council
ARIS	adaptive resolution imaging sonar
ASV	autonomous surface vehicle
BLM	Bureau of Land Management
BLOB	Binary Large Object
BOR	Bureau of Reclamation
BYOD	bring your own device
CAD	computer-aided design
CDL	California Digital Library
CHDK	Canon Hack Development Kit
cm	centimeter/s
CMOS	complementary metal-oxide semiconductor
CoDA	Center for Digital Archaeology
COLLADA	COLLABorative Design Activity
CRM	cultural resource management
CSS	Cascading Style Sheet
CSV	comma separated values
DBMS	desktop database management system
DEM	digital elevation model
DINAA	Digital Index of North American Archaeology
DIY	do-it-yourself
DoD	Department of Defense
DVL	doppler velocity log
EAV	entity-attribute-value
EDM	electronic distance measurement
EU	excavation unit/s
FAIMS	Federated Archaeological Information Management System
fMRI	functional magnetic resonance imaging
GIS	geographical information system
GCP	ground control point
GNSS	global navigation satellite system
GPR	ground-penetrating radar

GUI	graphic user interface
ha	hectare/s
hr	hour/s
Hz	Hertz
HDSM	high-density survey and measurement
ICE	Image Composite Editor (Microsoft)
iOS	iPhone operating system
INS	inertial motion sensor
IPinCH	Intellectual Property in Cultural Heritage
IT	information technology
KAP	Kaymakçı Archaeological Project
KARS	Keos Archaeological Regional Survey
km	kilometer/s
LABUST	Laboratory for Underwater Systems and Technologies (University of Zagreb)
LAN	local area network
LIEF	Linkage Infrastructure Equipment and Facilities
LOD	linked open data
LTE	Long-Term Evolution
m	meter/s
masl	meters above sea level
MEMSAP	Malawi Earlier-Middle Stone Age Project
MOA	memoranda of agreement
MOOC	Massive Online Open Course
NGWSP	Navajo-Gallup Water Supply Project
NeCTAR	National eResearch Collaboration Tools and Resources
NEH	National Endowment for the Humanities
NHPA	National Historic Preservation Act
NPS	National Park Service
NRHP	National Register of Historic Places
NSF	National Science Foundation
OCR	optical character reader
OS	operating system
PA	programmatic agreement
PAP	pole aerial photography
PARP:PS	Pompeii Archaeological Research Project: Porta Stabia
PATA	Proyecto Arqueológico Tuti Antiguo
PBMP	Pompeii Bibliography and Mapping Project
PDA	personal digital assistant

PIARA	Proyecto de Investigación Arqueológico Regional Ancash
PKAP	Pyla-Koutsopetra Archaeological Project
Pladypos	PLAtform for DYnamic POSitioning
PLoS	Public Library of Science
PQP	Pompeii Quadriporticus Project
PZAC	Proyecto Arqueológico Zaña Colonial
QA	quality assurance
QC	quality control
QR	quick response
REVEAL	Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy
ROS	robot operating system
ROV	remotely operated vehicle
RRN	Reciprocal Research Network
RSS	Rich Site Summary
RTK	real-time kinetic global navigation satellite system
SfM	structure from motion
SHPO	State Historic Preservation Office
SKAP	Say Kah Archaeological Project
SLAM	simultaneous localization and mapping
SMU	square meter unit/s
SU	stratigraphic unit/s
SVP	Sangro Valley Project
TCP	traditional cultural properties
tDAR	the Digital Archaeological Record
UAV	unmanned aerial vehicle
UNASAM	National University of Ancash, Santiago Antúnez de Mayolo
UQ	University of Queensland
USACE	U.S. Army Corp of Engineers
USBL	ultra-short baseline
USFS	U.S. Forest Service
USV	unmanned surface vehicle
UTM	universal transverse mercator
XML	Extensible Markup Language



3.2. Measure Twice, Cut Once: Cooperative Deployment of a Generalized, Archaeology-Specific Field Data Collection System

*Adela Sobotkova, Shawn A. Ross, Brian Ballsun-Stanton,
Andrew Fairbairn, Jessica Thompson, and Parker
VanValkenburgh*

[W]hen people use [mobile devices] they end up just using technology to consume things instead of making things. With a computer you can make things. You can code, you can make things and create things that have never before existed and do things that have never been done before.

That's the problem with a lot of people . . . they don't try to do stuff that's never been done before, so they never do anything, but if they try to do it, they find out there's lots of things they can do that have never been done before.

Russell Kirsch, 20th-century computing pioneer (Runyon 2012)

Archaeologists face an immediate, fundamental decision once they decide to digitize field data collection: put together a solution from several pieces of general-purpose, usually proprietary, software aimed at the commercial market (often supplemented by continuing use of paper); commission a bespoke mobile application tailored to their specific project; or use one of the growing number of “generalized,” often open-source, platforms designed specifically for archaeological fieldwork. Generalized software allows deep customization, adapting to the user's approach and procedures rather than requiring the user adapt to the software, while still being designed specifically for archaeology. Examples of open-source, generalized (or at least highly

customizable) software developed with archaeological data in mind include the Archaeological Recording Kit (ARK; <http://ark.lparchaeology.com/>; see also Dufton, Ch. 3.3), Heurist (<http://heuristnetwork.org/>), and the subject of this paper, the Federated Archaeological Information Management Systems (FAIMS; <http://faims.edu.au/>) mobile platform. Bespoke applications can meet the particular requirements of archaeological fieldwork, but producing and maintaining them exceeds the resources of almost all projects or institutions. Commercial data-entry applications offer lower barriers to entry (although it remains resource-intensive in the long run), but they adapt poorly to the exigencies of the field and require archaeologists to make many compromises. Generalized, open-source tools designed for field research bring the advantages of bespoke software within reach of “typical” projects.

Perhaps more importantly, generalized tools also allow archaeologists to *participate* in software development, not merely consume software. Such co-development involves a partnership between field archaeologists and a software development team. This partnership can ease the transitions from paper to digital fieldwork, illuminate the advantages digital approaches offer, and ensure that software is fit-to-purpose. Its benefits and rationale are analogous to those of Open Context’s model of “data sharing as publication,” where data editors collaborate with data creators (Kansa, Ch. 4.2). In this paper, three project directors who co-developed and deployed a FAIMS recording system in collaboration with the FAIMS team report their experiences. Having first-hand experience of co-development, they reflect on the challenges and benefits of working with the FAIMS project team to produce a customized implementation of a generalized field recording system.

THE FAIMS PROJECT

The FAIMS project is a university-based, e-research initiative that was launched in 2012 to develop national, domain-wide information management infrastructure for archaeology and related disciplines (Ross 2013, 2015; Sobotkova *et al.* 2015). It was initially based at the University of New South Wales, Sydney, and funded by a grant from the Australian National eResearch Collaboration Tools and Resources (NeCTAR) eResearch Tools program (RT043; AUD \$949,500). In consul-

tation with Australian and international archaeological communities, the FAIMS project developed a generalized, mobile, offline, multi-user collection platform for structured, free-text, geospatial, and multimedia data (the “FAIMS mobile platform,” discussed below), which entered public beta release in November 2013. The project also supported enhancements to the Heurist online data refinement and analysis service developed at the University of Sydney, and established an Australian implementation of the Digital Archaeological Record (tDAR; <https://www.tdar.org/>), an online data archive developed by Digital Antiquity. In 2014, the FAIMS project received an Australian Research Council (ARC) Linkage Infrastructure Equipment and Facilities (LIEF) award (LE140100151; AUD \$945,000 total ARC funding and university co-investment), allowing a second phase of development that emphasized field deployments of the mobile platform at partner universities, three of which are presented in this paper. Experience from these deployments informed ongoing development of FAIMS software, resulting in the release of FAIMS 2.0, the current production version, in November 2014 (FIGS. 1, 2). The project moved to Macquarie University, Sydney, in January 2015.

The sustainability plan of the FAIMS project involves iterative applications for research infrastructure funding, primarily through the ARC LIEF program. LIEFs are matching grants that require partner organizations (primarily universities) to contribute approximately one-third to one-half of the total budget. Universities that commit cash to a LIEF receive a commensurate amount of support from the FAIMS project; the two Australian projects discussed in this paper fall into this category. This infrastructure grant income is supplemented by fees charged for customization, field support, server hosting, and other services (a typical open-source business model; cf. Raymond 2001: 136; Popp 2015); the United States-based project discussed here paid for services directly. To that end, we encourage research projects that plan to use FAIMS to include an appropriate budget line in their grant applications. To date, fees have accounted for about 5% of the FAIMS budget, with infrastructure grants constituting the other 95%—although these figures exclude in-kind contributions of time by academic staff and other participants, which, for example, total approximately \$100,000 per year at Macquarie University alone. We envision that within five years, service fees will constitute perhaps 25% of our budget, but the project will likely remain largely

Context

GEN GEOL REL SAMP ART/ECO FILES REVIEW

Site Name: [?] Area: [?]

Square: [?] Context Number: [?] LotID: [?]

Date Opened (YYYY-MM-DD): [?] Wet Sieved: [?] [?] [?]

Excavation Method: [?] [?] [?]

☐ Hand-Pick

☐ Trowel

☐ Pick

☐ Other

Your Interpretation: [?] [?] [?]

No Observation

Context Comments: [?]

Artefacts/Ecofacts Present: [?] [?]

☐ None

☐ Flakes

Boncuklu 2014 Module: Context Tab

Boncuklu Excavation Module 2015 > Home > Context

GEN-ERAL MEA-SURE INT FEA-TURE REL ARTE-FACTS SAM-PLER ADD VALIDA-TION

Validate

Trench: [?] Context Code: [?] Brief Description: [?]

H: [?] 1

Grid X: [?] Grid Y: [?]

Approx location in area: [?]

Date started: [?] Excavation Method: [?]

2015-12-02 18:42:30 GMT+11:00 ☐ Hand-pick

Excavators: [?] ☐ Trowel

☐ Pick

☐ Other

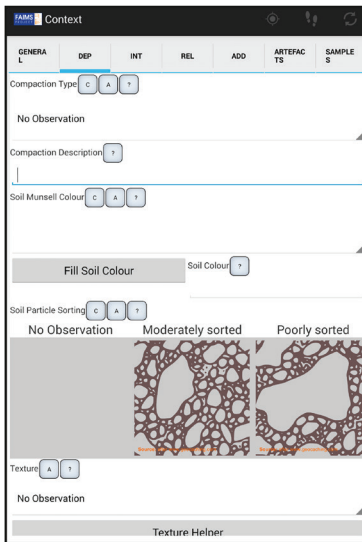
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Context Type: [?]

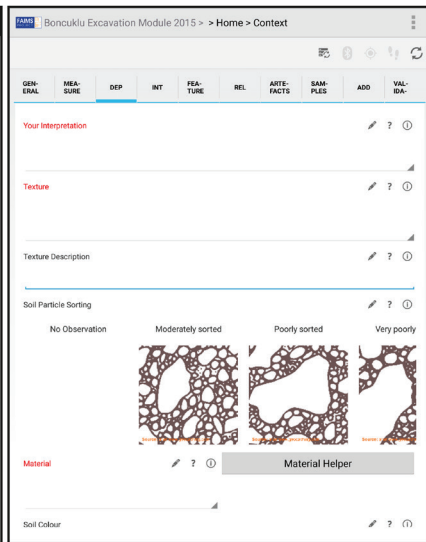
No Observation Negative Element Deposit Struct.

Boncuklu 2015 Module: Context Tab

Figure 1: The “Context” tab in the Boncuklu excavation module in 1.3 and 2.0 version of FAIMS on Nexus 7 and Nexus 9, respectively, showing improvements in interface design.



Boncuklu 2014 Module: Deposit Tab



Boncuklu 2015 Module: Deposit Tab

Figure 2: The “Deposit” tab in the Boncuklu excavation module in 1.3 and 2.0 version of FAIMS on Nexus 7 and Nexus 9 respectively, showing differences in the rendering of picture dictionaries, annotation and certainty icons, module path and indicator bar.

dependent upon infrastructure grants and in-kind contributions. This funding allows the FAIMS project to employ a professional software engineering team (as well as student programmers) to ensure that our software meets high standards and avoids some of the shortcomings often associated with academic software (which often remains a prototype, built to run on specific infrastructure at a particular time, making it fragile and difficult to reuse in new contexts; cf. Sun 2012; Might 2015).

THE FAIMS MOBILE PLATFORM

The “core” software of the FAIMS mobile platform does a lot of the “heavy lifting” required of archaeological software: automatic synchronization of data among multiple users, maintaining record histories for review and reversion of changes, backup, data export, internal and external sensor management, and provision of a mobile GIS. Since FAIMS is generalized, however, it has to be customized for each project. Such a “deployment” involves tailoring the core software by creating or modifying “definition documents,” primarily Extensible Markup Language (XML) files, which produce customized data collection “modules” (Ross *et al.* 2015). Each module accommodates specific data and workflow requirements, as required by different approaches to archaeological survey, excavation, and artifact processing. So, for example, the “Boncuklu excavation module” is an implementation of FAIMS customized for single-context recording method as it is practiced at the excavation of a Neolithic tell in Turkey (see below).

The FAIMS project uses GitHub, an online version control tool for collaborative software development, to publish and manage individual modules (<https://github.com/FAIMS>; cf. Ross *et al.* 2015). Software or other text documents stored on GitHub can be downloaded, edited, copied, and adapted at will. As an example, in 2013, the FAIMS team developed a “deluxe excavation” module, which provided the foundation for the three deployments discussed here (Boncuklu Höyük in central Turkey, the Malawi Earlier-Middle Stone Age Project (MEMSAP), and Proyecto Arqueológico Zaña Colonial (PAZC) in Peru). This module was duplicated (“forked”) and modified to meet the needs of each project. Using GitHub not only made the definition documents for all four modules (the original plus the three adaptations) publicly available, but it also allowed for the most useful changes to each of the

derivative modules to be incorporated (“pulled”) back into the original “deluxe excavation” module. Users can now choose whichever of these four modules best fits the requirements of their own fieldwork (the three customized modules can be found in the Supplementary Material folder). It has been a guiding principle of FAIMS to build a growing library of modules that accommodate as many archaeological activities, and variations of them, as possible.

Customizing and Deploying the FAIMS Mobile Platform

The Mobile Platform consists of an Android mobile application (available on Google Play) and a Linux server (available on GitHub). All FAIMS project software is free and open source (GPLv.3 license). The mobile software will run on most recent Android devices (current specifications are available from <http://www.faims.edu.au/>). The server either can be a local, physical computer or can reside online. Users with the time and expertise can implement FAIMS themselves, or they can purchase that service from the FAIMS team. Two small projects, both undertaken by doctoral students, have successfully customized and deployed their own systems. Most users, however, have chosen to purchase customization and support services from the FAIMS team; to date, we have created 19 workflows for 17 projects and supported 11 of them in the field since the public release of our software in November 2013. That number is likely to double by the end of 2017.

Users can establish a local or online server themselves by installing Linux (specifically, the most recent Long Term Service release of Ubuntu) and executing a few commands to download and install the FAIMS server software. Once in the field, the server is essentially an appliance that synchronizes devices and performs automatic backups, requiring little attention. Users only access the server (via a Web interface from any other device on the network) to adjust controlled vocabularies, manage users, view record histories and revert changes, export data, and perform other administrative tasks. For those new to the system, the FAIMS project offers temporary, pre-configured, online servers for trials at no cost.

For users who want to purchase a pre-configured server, the FAIMS project has established relationships with vendors in Australia and the United States who can provide and support local or online servers. Purchasing a pre-configured local server with all necessary hardware

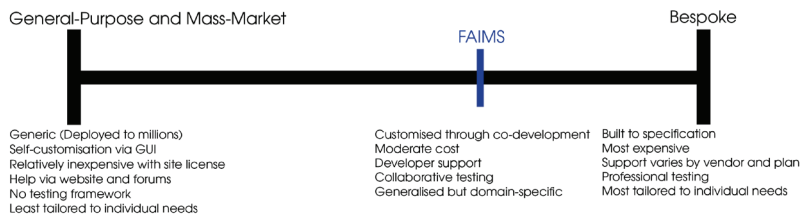


Figure 3: The spectrum of customization options.

costs AUD \$1,700–\$3,500 from one of these vendors (excluding tablets). Alternatively, an online or local server can be leased for approximately AUD \$150–\$200 per month. In the case studies presented below, Boncuklu and MEMSAP purchased preconfigured local servers, while PAZC used an online server (but later switched to a local server in a subsequent season).

After the establishment of a server, do-it-yourself users can customize the mobile application for their own work in four ways, which require progressively more effort and technical expertise, but also allow more nuanced control over the resulting module:

1. Reuse an existing module as-is, which requires only downloading the application from Google Play and selecting the desired module from a list;
2. Use Heurist (an online data service), which provides a graphic user interface for the generation of definition documents (suitable for relatively simple modules);
3. Use a simplified module generator, which requires writing a single XML file that generates definition documents (suitable for modules of moderate complexity);
4. Modify an existing module, or create a new one, by editing the definition documents directly, which requires proficiency with XML and BeanShell (a scripting language).

The FAIMS project has developed extensive documentation to assist users who want to establish their own server and customize their modules using any of these approaches (<https://www.fedarch.org/support/#2>), which was improved recently through a 2015 NeCTAR grant specifically targeted at user support. The project team provides free support on a time-available basis.

Thus far, however, most users have approached the FAIMS team for customization services, including those in the case studies presented here. In such cases, we employ a combination of the third and fourth methods described above, automating whatever code generation we can to reduce development costs, while maintaining fine-grained control over data structures, user interfaces, and automation where necessary. When a project hires the FAIMS team to adapt an existing module or develop a new one, this service generally costs approximately AUD \$1,500–\$15,000 per season for the mobile

platform, depending on the complexity and novelty of the recording system required. Deployments of a module for subsequent seasons are usually less expensive because users only pay for changes and support. Customization and support work for the Boncuklu and MEMSAP projects presented here, for example, was valued about \$15,000 each for their first year of deployment (but only \$3,250 for a subsequent deployment for Boncuklu). Because the PAZC project was willing to reuse an existing module, their first year cost only \$900 (a subsequent deployment cost \$2,400, after they identified some additional modifications), illustrating the savings that redeployment can offer. These costs include support for the duration of fieldwork and assistance with data export (we fix bugs and other errors at no additional charge, but users pay for significant in-field changes and priority support). As will be seen below, customization and support costs of this magnitude can be largely recouped from later savings in data digitization and reconciliation, aside from any other benefits of digital recording (cf. Spigelman *et al.*, Ch. 3.4). Finally, the FAIMS team also offers development-in-trade for in-kind help with testing, documentation, and other activities to students, another common practice in open-source communities.

It is our hope that by building free and open-source software to high standards using research infrastructure funding, by providing extensive documentation and as much support as possible for do-it-yourselfers, by building a library of modules for various activities, and by offering customization, deployment, and support services at a reasonable cost, we can deliver purpose-built field-recording software to projects and organizations who otherwise could not afford it.

BETWEEN OFF-THE-SHELF AND BESPOKE SOFTWARE

Software development strategies fall along a spectrum (FIG. 3). On one end are consumer-grade, “general purpose,” desktop database management systems (DBMS) with graphical user interfaces, which put “simple” customization into archaeologists’ hands. At the other end sits bespoke software development, where archaeologists (for example) request features they want, as they would select cloth from a high-end tailor making a custom suit, and software developers produce a tailored mobile application from scratch.

FAIMS lies near the middle of this spectrum. Compared to a general-purpose DBMS, FAIMS is “generalized” in the sense it has no predetermined data schemas or user interface, instead offering a degree of control over data structures and forms similar to DBMSes like Microsoft Access or FileMaker Pro. It is not general-purpose, however, in that it has been purpose built to perform well under difficult field conditions and includes functionality specifically requested by archaeologists (through stocktaking activities, cf. Ross *et al.* 2013). As a result, for a customization effort similar to that required by a general-purpose DBMS, researchers get software optimized for archaeological fieldwork.

For illustration, one example of a fieldwork-specific feature is the capacity of FAIMS to synchronize across many devices in a degraded-network environment. Most DBMSes store data on a single server that can be accessed by many clients. Mobile applications also typically use this architecture, which is simpler and has performance advantages. These applications, however, expect a regular—if not continuous—connection to a server. Archaeological fieldwork frequently suffers from intermittent or disrupted network communications. To accommodate these conditions, devices running FAIMS have no need for a continuous connection to maintain data integrity; they happily operate offline and synchronize whenever a Wi-Fi network is available (according to configurable rules). The FileMaker application and DBMS, conversely, have been designed for more “normal” deployment situations, and they operate grudgingly in a network-degraded field environment, requiring work-arounds when asked to collect data simultaneously on multiple offline devices. An example of such work-arounds regarding synchronization and offline use is seen with FileMaker:

For real-time access to the most up-to-date information, host solutions with FileMaker Server. For this option, purchase of concurrent connections is required along with access to a local wireless or cellular network. Or to share your solutions offline, copy files to FileMaker Go using iTunes File Sharing, email or AirDrop (FileMaker 2015).

Keeping a change history and managing geospatial data are even more difficult. It does not make sense for FileMaker to optimize for

these unusual conditions, as they require significant trade-offs in complexity and performance, and return benefits only in specific and limited situations. FileMaker was designed for everyone; FAIMS was developed around the expressed requirements of archaeologists to manage the high-friction environment of fieldwork.

FAIMS offers similar optimization for other issues specific to fieldwork, such as the need to collect a variety of data, work in multilingual settings, and promote the production of compatible datasets for large-scale, synthetic research. FAIMS tightly binds the diverse data fieldwork generates (e.g., structured, free text, geospatial, and multimedia), connects to internal and external sensors, allows tracking and reverting changes to the data, supports customizable data export in a variety of common formats, translates the interface between languages or conceptual vocabularies, and maps local concepts to open, linked-data vocabularies (thus promoting both syntactic and semantic data compatibility; cf. Limp 2011: 277–279; Wallrodt, Ch. 1.1). These fieldwork-specific capabilities get inherited by each module; they need not be newly programmed upon user request. They are all there waiting on users to take advantage of them (or not). This combination of flexibility and domain-specific features is what makes FAIMS “generalized.”

A bespoke Android or iOS app, *if properly resourced and designed*, may outperform FAIMS for any *single* data collection task, but at considerable cost. The requirements gathering, planning, development, and testing required to produce software reliable enough for field archaeology are expensive and demanding. Even after development is “complete,” software has significant maintenance costs such as bug-fixing and keeping up with the biennial mobile OS update cycle (not to mention updates to other components of the software “stack” that underlies every application). These development and maintenance costs are beyond the resources of all but the best-funded projects and organizations, such as is iDig, created by the Athenian Agora Excavations of the American School of Classical Studies (<http://idig.tips/>; cf. Fee, Ch. 2.1). Because the core FAIMS software is common to all deployments, however, the fixed costs of development and maintenance can be shared across many users, projects, and institutions. Improvements that benefit all users can be made incrementally as resources come available. This shared core library also allows customization and deployment to be accomplished more quickly than bespoke development. A generalized, but fieldwork-specific,

application has the potential to attract a large enough user base to sustain it (cf. Kansa, Ch. 4.2).

THE NATURE OF CO-DEVELOPMENT

Participating in open-source development is different from buying software from a vendor. There are responsibilities, trade-offs, and significant benefits. Instead of purchasing a finished product, which can either be accepted or rejected, open-source tools can be re-invented and co-developed to fit specific needs. As a generalized platform, FAIMS must be customized by the researchers who use it. This co-development increases the likelihood that individual projects will achieve their goals, but it also requires archaeologists' active participation and willingness to reconsider information management during fieldwork.

Developing a data capture and management system for an archaeological project using FAIMS constitutes a miniature software deployment project. To an extent, the same is true of development using desktop DBMSes like Microsoft Access or FileMaker, but FAIMS is perhaps more transparent about it, in that development is accomplished through editing text files rather than manipulating a graphic user interface. The apparent ease of development provided by mass-market DBMSes seduces users into thinking that information systems can be built and maintained with minimal investment or technical expertise. Eventually, however, even desktop DBMSes require considerable scripting to accommodate archaeological workflows. As a result, the landscape is littered with half-finished or abandoned databases created using desktop systems (including, admittedly, several built by some of this paper's co-authors). Because the software development looks easy, projects under-resource it.

FAIMS treats complex archaeological work with the seriousness it deserves. The FAIMS approach, partly dictated by the nature of the software and partly by our experience, has us treat each deployment as an authentic, miniature software development project that requires proper "scoping" (requirements gathering, software design, and development planning), coding, and "quality assurance" (testing at each step of development to ensure that software works and is fit-to-purpose). As such, the authors believe that our experience also offers lessons to those who choose to customize commercial DBMS software.

THREE CASE STUDIES AND THREE THEMES OF OBSERVATION

The three FAIMS implementation case studies presented here include: (1) a Neolithic tell excavation in central Turkey, (2) a Middle Stone Age excavation and surface survey in Malawi, and (3) a late Prehispanic/early Colonial excavation in coastal Peru. Three researchers, one from each case-study site, generously offered to share and discuss their experiences deploying FAIMS during 2014 fieldwork. They took the time to complete post-project questionnaires, and also exchanged many emails and chat messages with the FAIMS team before, during, and after their fieldwork. These sources provide the quotations below; their complete, unedited communications with the FAIMS project are available via the digital supplement to this volume (see the files contained in Supplementary Material 1: “Fairbairn: Boncuklu Case Study”; “Fairbairn: Chat Log.pdf”; “Thompson: Malawi Case Study”; “VanValkenburgh: PAZC Case Study”). Their observations can be woven into three themes, demonstrating common challenges, concerns, and benefits shared across all three projects.

Andrew Fairbairn, an Australian Research Council (ARC) Future Fellow and Associate Professor at University of Queensland (UQ), co-directs excavations at the Neolithic tell of Boncuklu Höyük (Boncuklu) in central Turkey (Baird *et al.* 2012; <http://boncuklu.org/>). About his site, he wrote:

One peculiarity of the site is its extremely fine layering and the complex intercutting of archaeological features, caused by rebuilding of houses on the same site time and time again. . . . [a single context in] Boncuklu may be resolved within <5 cm of deposit. . . . As a result, excavation has necessarily been fine-grained, utilising a single context recording method better to understand the subtle interrelationships of the site’s building sequences and extra-mural areas. Single context recording describes each deposit, cut and feature in detail, including spatial coordinates and contexts (artefacts, samples) as well as basic descriptives (form, size, etc).

Jessica Thompson, then an ARC Postdoctoral Research Fellow also at UQ (now an Assistant Professor at Emory University), directed the

Malawi Earlier-Middle Stone Age Project (MEMSAP), which included excavation and pedestrian survey (Thomson *et al.* 2015; <http://memsap.org/>). Of their project, she wrote:

MEMSAP based its excavation recording system on a single-context form-based system modified from Marean *et al.* (2010). Given the range of backgrounds represented on the project, it was desirable that the recording protocols contain as many checks and constraints as possible, but also that there was ample opportunity to freehand any observations that may not fit into one of the pre-designated categories.

Parker VanValkenburgh, then an Assistant Professor at the University of Vermont (now an Assistant Professor at Brown University), directed the Proyecto Arqueológico Zaña Colonial (PAZC), a multidisciplinary project focusing on late Preshipanic and early colonial Peru that includes excavation (VanValkenburgh 2012). He wrote:

In our 2012 field season at Carrizales, PAZC team members recorded data using a single-context recording system on paper forms. We also drew orthographic illustrations on large-format millimetric graph paper and captured digital photographs of the tops and bottoms of each excavated context.

THEME 1: UPFRONT COSTS, BACKEND PAYOUTS

One of the themes that emerged from these case studies involves the shift in time and energy from digitization and cleansing of data at the end of the project, to scoping, development, and testing of recording systems at the beginning of the project. Even considering the up-front time requirement, however, time savings at the end of the project were substantial—even revolutionary; an entire season's data could be retrieved immediately, without tedious digitization and the errors it inevitably introduces (cf. Spigelman *et al.*, Ch. 3.4).

Scoping and Development

Requirements gathering, planning, and development is a lengthy, iterative process that requires frequent communication, consultation, and feedback. Established projects with stable procedures have an advantage during software customization, since they can articulate requirements and priorities quickly and coherently. Even so, field projects with complex workflows still require several months for development to ensure that the end product satisfies their needs. Thompson commented on the numerous discussions and feedback loops she engaged in during module scoping and prototype testing:

Prior to the field season, the FAIMS leadership team met with several of its partners at UQ, including those involved in MEMSAP. . . . Several hours were spent in discussions with all senior project personnel to ensure that all data types they wanted recorded were represented in the modules, and then after the workshop detailed plans for the tab layout and controls were developed mainly by the project leader but in consultation with other project personnel. . . . Ultimately only three iterations of the excavation module and two iterations of the survey module were needed before a functional system could be deployed in the field. However, this was likely because all of the data categories and relationships had been worked out—in paper version—over the course of previous field seasons.

Converting from paper to digital workflows is an involved and time-consuming process. It requires making the implicit knowledge embedded in paper forms explicit. Digital forms are also more formalized and restrictive than paper forms; relationships between entities, controlled vocabularies, and other aspects of the data model must be defined and encoded (cf. Gordon *et al.*, Ch. 1.4; Motz, Ch. 1.3, who had to write full protocol manuals to ensure users understood their data model). Paper forms can approximate the desired data collection strategy, with exceptions, omissions, and edge cases written in the margins or on the back of the form. Despite some FAIMS features like the “annotations” field embedded in all attributes where users can make contextual notes, which reproduce the freedom of the paper page (cf. Ellis, Ch. 1.2), digital forms must be more precise and complete, or

their primary advantage—the production of clean, consistent data—is lost. The conversion from fuzzy paper forms to sharp digital recording often instigates a thorough review and revision of existing recording procedures and workflows. Fairbairn noted the benefit of this revision process:

In the process of defining the parameters of the future FAIMS module I also got the opportunity to thoroughly review and refine the Boncuklu recording system to the last field and attribute, which identified some redundancies and allowed better definition of the attributes expected in the system.

The critical resource during software development is time, which may be allocated to scoping, to developing new features, to improving performance, or to testing, bug fixing, and ensuring fitness for purpose. Since time is a finite resource, these activities must be balanced against one another. At some point, the archaeologist must finalize their data model—their list of entities, attributes, and vocabularies—so that development can end and testing may begin, with enough time to fix and finalize the module before fieldwork starts. The “perfect” module may be a moving target, and the perfect can become the enemy of the good. Sometimes we should settle for good, but imperfect, software to do fieldwork. In order to collect useful data while controlling the time spent on scoping and development, Fairbairn recommends:

Consider your recording needs in depth well before deployment of your module and learn to articulate those needs explicitly. Time is money and imprecise, poorly articulated demands increased the developers’ time on this module. Provide precise instructions and well-articulated aims to your developers.

VanValkenburgh followed this advice, and his module was produced quickly:

The total time that elapsed between first contact with FAIMS leadership and deployment of the finished PAZC module was approximately three and a half weeks.

The PAZC module also benefited from reusing the Boncuklu module with some modifications (emphasizing the advantages of an open source, document-based customization strategy: modules can be rapidly modified and redeployed, while each new module or modification improves the whole system). The FAIMS team translated the Boncuklu module into Spanish and customized it where required by editing the Boncuklu definition documents, a process that required less than one week after the requirements were fully specified. The speed of production was possible because of VanValkenburgh's pragmatism and willingness to adapt an existing module. As this example illustrates, a system with a generalized core can spawn new deployments rapidly in a way that neither bespoke nor general-purpose systems can.

Testing and Training

To test, or not to test—that is the question: Whether 'tis nobler in the mind to suffer the slings and arrows of crashes and incorrectly implemented features or to allocate development time against a sea of trouble tickets and by opposing end them. To ship, to commit no more—and by shipping we end normal development and the thousand emails that development is heir to.

Brian Ballsun-Stanton (after a late night of bug-fixing)

Software development requires that scoping, programming, and testing be finite, limited, and in balance with one another. In the FAIMS experience, archaeologists tended to prioritize the development of new features at the expense of testing. This is hardly surprising, as feature development is exciting and novel, as opposed to the rote, but essential, work of testing. While feature planning is rewarding and creative, it must be kept in check, and it cannot outrun the resources available for ensuring performance, quality, and fitness to purpose: "Testing the module prior to fieldwork ensured it was technically functional, and allowed for communication of changes that would be hard done remotely" (Thompson).

All project directors tested their modules ahead of fieldwork, but eventually they all regretted not doing so more thoroughly, with more participants, and in more authentic situations.

Thompson realized the shortfalls of her own testing only when she was in the field:

Once in the field the use of modules revealed other usability issues that varied across the team. Simulation of fieldwork is highly advised here. Or better yet, training a project novice in the use of the module is where potential misunderstandings (of the workflow) become apparent.

Fairbairn, too, found a problem of fitness-to-purpose on the first day of fieldwork that had slipped through his earlier testing: “A significant problem with the app design has arisen. It is one that I flagged earlier but somehow it got through my later checks . . .”. Fairbairn’s module had to be updated while live in the field. Live updates, designed for situations like this one (where a problem is identified after deployment) can be useful (cf. Fee, Ch. 2.1), but they pose risks of failure due to the lack of testing and should be avoided.

Hardware can cause its own problems, such as device-specific bugs. Software that worked during internal testing by the FAIMS team (or even by archaeologists prior to fieldwork) did not always work on different tablets, even if they were made by the same manufacturer. These compatibility problems are the price paid for the wide range of devices offered within the Android ecosystem. It therefore proved necessary to test the FAIMS mobile platform on each device. Fairbairn explained the importance of specific and realistic testing:

Test your module and, if you are using multiple tablets, the server and its system extensively before you depart for the field with real data including every field and recording type you may use; bugs may be hard to find and you need to be sure the system works for your needs.

Several months may sound like a long time for complex module development, but for a typical software development project it is a very short timeframe. While the FAIMS approach of customizing generalized

software can produce recording systems faster than bespoke software development (Kitchenham *et al.* 2002), the modules still require extensive testing. The amount of testing necessary is a product of the complexity of the module, the degree of automation and flow logic it incorporates, and other features like GIS integration, translation, or multimedia file management. The rigor of testing determines the quality of the fieldwork experience and resultant data, which from the perspective of the FAIMS team, make it worth a significant investment of everyone's time.

The Payoff: Clean, Granular, Digital Data

After fieldwork, the FAIMS team asked each of the project directors to reflect on the design, development, and deployment of their module, and tell us what they found the most worthwhile payoff for their efforts.

Fairbairn appreciated having his data available to him shortly after the end of fieldwork, especially the ease of export into the desktop software he normally uses (Microsoft Access). He received his comma separated value (CSV; a standard spreadsheet-type format) data files and created an Access database from them, all in the time before the paper forms (used as a backup to FAIMS as part of the transition to digital recording) arrived at Australia:

[I have received the CSV file and] the data are present and useable. I am now waiting for [the other project director] to send me the forms . . . (excerpted from Google Hangouts between Brian and Andrew Fairbairn, 18 September 2014)

VanValkenburgh enjoyed the “richness and integrity” of digitally-born data:

[. . .] our final review of data collected by the PAZC in 2014 suggests that using FAIMS improved both the richness and integrity of our data. Context descriptions are generally more detailed, and the range of fields in the FAIMS default module meant that project members recorded types of data (such

as parameters of soil matrices and inclusions) that we had formerly treated in an inconsistent fashion.

Thompson agreed, noting the benefits would accrue over multiple field seasons:

The FAIMS data outputs [...] required [...] much less cleaning, organization, and streamlining for consistency than transcribed data. [...] However, it was clear that once this initial hurdle was overcome it would be far faster and error-free to append FAIMS data from subsequent seasons onto these merged databases than to return to a paper form recording system.

The data management benefits were especially clear in the MEMSAP survey team's change of opinion over the quality of survey data when collected with tablets. Thompson emphasized the improved consistency of data and the value of having various types of data (structured, geospatial, and image) automatically linked, something that is difficult to implement with general-purpose database software:

When the survey data were examined and analysed during post-season work, it became very clear to the survey team that the tablets presented a huge advantage. During post-processing all the data were tied together already and did not require the manual integration of paper forms with separate photo logs and GPS records—nor did they suffer from the inevitable transcription error that in this case cost at least six person-hours to investigate and rectify. There were fewer errors made in data recording with the tablets, and the pre-defined categories made the data far easier to sort, search, and analyse. When the scope of data entry, cleaning, analysis, and archiving is considered, the tablets saved at least eight person-days of work, although this may have been an extreme case because one of the main post-season challenges [during previous seasons] was the integration of both paper and tablet data into a single database.

Fairbairn also quantified the time-savings and cost-benefit of clean, born-digital data to his project:

The greatest gains in the FAIMS system were found after the excavation season was finished with post-processing of the data and checking taking 2–3 hours in comparison to several hundred hours for entry of the >300 context records generated in a typical season. This saving in paid RA time equates to c. AU\$5,000–10,000 per annum. Post-processing required specialist input by FAIMS to extract CSV files from the data tarball [.tar, a common Linux file archive similar to .zip], but the outcome was easily accessible and useable data which can be uploaded to a database. In the Boncuklu case the CSV tables did not match the legacy database, however, some relatively quick (0.5–1 day) [edits] ... allowed the data to be uploaded. The benefits to the excavation project in financial/labour terms are hugely significant, equating to a total of 1–1.5 days of handling time using FAIMS against 25–30 days when not in use per annum, in other words a 95% labour saving.

Finally, Fairbairn discovered an unexpected benefit of having his digital data available immediately: the timely discovery of errors. “I also can see all the inconsistent entries that were made by people who should know better.” His data was digital and ready for review promptly at the end of the season, which revealed problems that would otherwise have gone undetected until the paper forms were digitized—perhaps months later—when the errors would have been far more difficult to correct. Even when digital data creation does not prevent errors, it exposes them.

While many projects prefer to collect data first and spend effort cleaning it later, our partners chose to invest effort before fieldwork, in order to have cleaner, richer data for immediate analysis. Learning the capabilities of FAIMS software and engaging in the scoping and testing required by co-development all took more time before fieldwork than producing paper forms would have. After fieldwork, however, they got rich, well-structured data at the push of a button, while errors and inconsistencies in the data could be detected immediately rather than during later digitization or processing. Fairbairn and Thompson could readily quantify the savings in time and resources this trade-off produced; based on their experience, most projects would likely come out ahead.

The Importance of High-Quality Support

Exceptional support is necessary when deploying new technology in the field, especially software that is purpose-built for the research community (Fisher *et al.* 2010). Only the availability of high-quality and timely support can provide the peace of mind necessary for archaeologists to risk moving from commercial software to new systems designed specifically for our domain. The FAIMS team's provision of such support proved crucial to the success of field deployments. To date, the FAIMS project has provided support as part of the module development package.

Thompson makes the importance of support very clear:

The app has been such an incredible advantage in terms of workload, data quality, and a number of other data management issues with which archaeologists regularly have to deal. It readily links disparate data types that are otherwise stored separately—such as photographs, tabular logs, and context relationships. I can see this user-friendly app being easily transferrable to other projects, and the support team has been brilliant. The hardware system was also quite remarkable in the way that it collected data, then synced and backed it up daily. Even projects like ours where we have no electricity on site can use the setup as long as there is power back at the home base. There were the usual start-up bugs, but the FAIMS team has already done an immeasurable amount of work to remedy all of them. From this already very exciting start, I can only see the FAIMS initiative becoming even more of a boon to archaeologists everywhere.

From the perspective of the FAIMS team, the biggest challenges were (1) communicating with archaeologists in remote locations, and (2) reproducing software errors back at our office. The stochastic nature of communication across time zones, often using unreliable channels, hampered technical support. Instruction in the effective reporting of bugs and other problems was also necessary, especially from remote locations under the stress of fieldwork. Once identified and reproduced by the FAIMS team, bugs were quickly fixed, unclear workflows were explained, and alternative paths around design shortcomings

were developed—but accurately reporting problems so that they can be reproduced is an acquired skill.

Over time and with use, software becomes more mature, and fewer bugs and problems arise. Developers and users can also cooperate to produce documentation that gradually replaces live support. For the innovators and early adopters introducing new technologies to complex projects, however, there is no substitute for patient, timely, and comprehensive support from developers.

THEME 2: TRADE-OFFS AND SHARED LESSONS

The shared responsibilities of developers and researchers are perhaps clearest in the context of the trade-offs between features and performance that must be made during the production of a field recording system. Each of these choices can have serious consequences when the final system is put under the stress of a full deployment. Two seemingly minor decisions, the use of complicated autonumbering, and the choice between local and online servers, offer examples of such trade-offs.

Legacy Features vs Performance:

How to Auto-Generate Smart Context Numbers

One of the major deployment challenges the FAIMS team experienced was archaeologists' requirement that FAIMS reproduce complicated context numbering schemes. These numbers did more than identify a context, they also encoded multiple pieces of information about it. Archaeologists wanted these numbers to be generated automatically and validated against all other records in the database to ensure they were properly ordered and unique.

Some of the project directors asked for auto-generated context “numbers” (actually alphanumeric identifiers) that would conform to legacy systems inherited from paper forms; for example, “Context name|HHAB” (Fairbairn) or “2228|SS|11|I|F5” (Thompson). These identifiers had to be generated according to specific rules to avoid duplication, ensure sequential numbering, and eliminate gaps (i.e., reuse identifiers that had been deleted). While FAIMS did automatically generate such identifiers, doing so slowed performance. Each

time a new context was opened and an identifier generated, the software had to read every record in the database, parse related records to determine the next appropriate identifier, and write the new number according to specific rules, all the while checking it against a growing list of existing identifiers for duplication, omission, and sequential order. The FAIMS team anticipated that this process would slow the software down, but it was difficult to communicate the seriousness of the threat. Performance degradation was barely perceptible during testing, which involved only a few records, but it worsened exponentially as the database grew (more precisely, as a square function of the number of records). Fairbairn commented: "More serious was the slowdown of the system halfway through its period of use. A record which initially took 20 minutes to input took over an hour due to slow syncing and updating." VanValkenburgh agreed: "These improvements (digital data) have come at a cost—namely, less efficient data collection in the field. While we have yet to keep time-on-task records for either paper-based recording or FAIMS, project members universally reported that data entry using FAIMS took longer than using our previous analog system."

Thompson's "2228|SS|11|I|F5" identifier, for example, encapsulates the distinct attributes of LotID, Site Code, Context ID, AreaCode, and Grid Location Reference. Five variables combined into one code may be easy for humans to read (although they can become obscure to future users of the data if coding sheets are not included with the data), but it is resource-intensive for machines to parse, especially when each variable is subject to a different set of rules. The implementation of this five-variables-in-one-field feature was possible, but it reduced performance and cost significant development time, which could have been better spent on other features or on testing.

This slowdown was avoidable because the actual information encoded in the context identifier can be captured in ways that do not compromise performance. Those five pieces of information did not have to be forced into the context identifier. Instead, they can be stored normally in five separate fields. The critical part of the identifier (the context number) can be automatically incremented from a manually assigned starting number (a "seed"). Assignment of seeds to individual devices, combined with server-side validation after all devices synchronize, ensures uniqueness of the critical portion of the overall identifier without performance degradation. The five separate

fields can be concatenated on export into a combined identifier to maintain the expected output.

Context numbering illustrates a larger issue. The question of “how closely do we duplicate our paper forms” is common to archaeological projects that are going digital. It is worthwhile to step back and consider the purpose behind legacy recording approaches, and weigh the problems and benefits of replicating them. Sometimes automation of a faithful replica is desirable and worth the cost in development time and performance, but at other times, a more robust digital approach will capture the purpose of legacy system, save time, improve performance, and offer additional benefits (in this case, verbose, human-readable context information that does not require decoding a complex identifier). In 2015, both continuing projects (Fairbairn’s and VanValkenburgh’s) chose simpler context numbering approaches.

Local vs Online Servers

Like most databases, the FAIMS mobile platform is a server-centered system, although client devices are coupled more loosely than usual to the server. The FAIMS server can take different forms. A virtualized instance of the server can run online (e.g., in the Australian NeCTAR Research Cloud) or on client laptops, or clients can commission a customized and preconfigured hardware package (“FAIMS-in-a-box”) with a dedicated server, network equipment, and certified tablets. Each hardware option has its trade-offs, which project directors will need to consider. Purchasing a FAIMS-in-a-box is more expensive than renting an online server and a suite of tablets for short-term deployments, but it offers greater reliability and faster synchronization, completely avoiding Internet connectivity and bandwidth problems that plague remote (and sometimes not-so-remote) locations. An online server required less attention from archaeologists than a hardware server, and was not subject to the wear-and-tear, intermittent electricity, and other hazards of deployment in the field. Different options are available because each project has different needs. Fairbairn had the best experience using FAIMS-shipped hardware:

Also, it is worth noting that the equipment—FAIMS-in-a-box—worked very well and with the exception of 1 tablet

screen—cracked when an item fell on it from the edge of the trench—came through the season in great condition. This was in spite of very dusty conditions and a somewhat unreliable electricity supply. The server worked throughout and the [wifi] provided excellent coverage (75–80% signal strength at 80m, the furthest excavation trench. The server hung only once, when the UPS plug was knocked out during a power outage, but was simply re-booted using an external keyboard.

Fairbairn's experience highlights the advantages of a local server. Thompson encountered a few more problems, but still used a FAIMS-in-the-box effectively. Debugging her setup under field conditions proved challenging, reinforcing the need for more authentic testing and comprehensive support for new technologies going into the field:

Setting up the network was also much more of a challenge when in the field than during a trial run in an office. There were several technical difficulties with the boot-up of the server, leading to many instances when data would not sync or when the server required an external keyboard and monitor to troubleshoot. The technical support provided by FAIMS was exceptional, and through a combination of their support and the fortuitous possession by project personnel of the needed hardware, all issues were overcome and have now been addressed by subsequent iterations of FAIMS hardware supply. This scenario would be much more difficult to negotiate in a field situation where internet is not readily available, and so in spite of the improvements that have been made, the necessity to fully set up and field test the entire system from start to finish before going to the field cannot be over-emphasized.

Instead of using a dedicated hardware server, VanValkenburgh attempted to install a virtual server on his laptop. Unfortunately, the installation failed, and an online server was deployed instead. His subsequent problems demonstrate the unreliability of the Internet in fieldwork settings:

We began with futile attempts to set up our own FAIMS server in the field house, in an Ubuntu virtual machine run off of a Windows laptop. Because we did not possess the resources to dedicate an entire machine to serving FAIMS, the development team provided us with access to their cloud server, and we set up a wireless access point in our dig house by running a 100-meter network cable from a nearby internet café and connecting it to a wireless router. Using this system, our upload speeds consistently averaged 25 Kbps—too slow for syncing, even when tablets were left to do so overnight. [I] then attempted to sync tablets on weekend trips to a city located one hour's drive away from Zaña. However, the large numbers of photographs we were attaching to our data records made complete syncs impossible. In the end, the FAIMS development team adjusted the PAZC module to allow syncing of our textual data alone, and we manually backed up all photographs onto external hard drives.

The lesson from these experiences echoes other aspects of co-development: reliability and performance require an investment from archaeologists as well as the development team. Local, dedicated hardware servers are more expensive than online servers, and they require that users test and maintain them, but they are faster and more robust than online servers.

THEME 3: DIGITAL RECORDING AND ARCHAEOLOGICAL INTERPRETATION—WHERE IS THE BENEFIT?

When asked to assess the direct impact of the digital recording on their research, project directors first emphasized improvements in the quantity, quality, and availability of data. Thompson reported: "Because FAIMS enabled data to be collected and processed so efficiently, we were able to collect more data, and this expanded the interpretations we could make from a field season of the same duration as when we used paper forms." Likewise, VanValkenburgh remarked that "the richness and integrity of our field data have both increased," an assessment echoed by Fairbairn "the conversion [to digital recording] increases quality of information available and makes post-excavation reconstruction of the site (the aim of the record) much easier . . . [it

also] sped up exchange of information on site between excavators and specialists." Although "efficiency" should not be the only, or perhaps the overriding, goal of digital research (cf. Caraher, Ch. 4.1; Kansa, Ch. 4.2), project directors nonetheless reiterated that enhanced speed, accuracy, consistency, and granularity represent important contributions of digital recording to archaeological interpretation.

The process of building data models and accommodating the precision of digital systems also compels archaeologists to review their recording practices more generally. Fairbairn observed:

[I]mportantly, the technology has opened up a broader dialogue about the recording process, increased awareness in the excavation group of the challenges and requirements of recording and opened a quite fixed system to change.

As part of that review, Fairbairn also noted how digital recording preserved previously undocumented interim steps of fieldwork:

[W]e have had a very archaic use of "official site photos" which are of the cleaned up contexts. Well, now everyone can take images as they go, including as contexts are under excavation (rather than tidy-for-archive shots) and this improves the chances of understanding the features and contexts we see.

More continuous recordkeeping, including of "messy" work-in-progress, not only helps researchers at a later time better understand what they have excavated, but may contribute toward both making workflows more transparent and "openly exposing the process of research" (Kansa, Ch. 4.2), thus improving the reproducibility and professionalism of field research.

Digital data collection may not immediately alter researchers' aims or interpretive agendas. Fairbairn began his response to questions about impact by observing that "so far conversion [to digital recording] has not changed our substantive research goals." VanValkenburgh concurred, admitting that "I'm not sure I feel comfortable at this point asserting that digital field recording methods led us, in linear fashion, to a series of different conclusions about the past." It can, nevertheless, allow researchers to follow hunches as the project progresses,

and to prove or disprove these intuitions later. VanValkenburgh also expects digital approaches to help separate real relationships among his data from accidents of preservation:

The richer, more organized field notes that FAIMS has provided us will allow me to efficiently move between scales of data during post-field analysis, comparing trends between sites and closely examining contexts with distinct patterns to evaluate whether they are the products of differences in past human behavior, post-depositional processes, or recording errors.

Similarly, Thompson thought that the standardization of digital data “clarified the analyses that were needed in order to address questions about the spatial relationships of artifacts, landforms, and other objects of interest.” The ability to make this sort of data-driven, quantitative argument improves the explanatory power and reproducibility of archaeological research, especially when it is combined with dissemination of the underlying data itself.

Finally, some of the benefits of digital recording may not be realized immediately. VanValkenburgh noted that the full impact of digital recording would not be clear until after post-fieldwork analysis and integration were complete. Looking even further ahead, digitally born data makes the timely publication of datasets more likely: “the ready availability . . . of our digital data is going to greatly facilitate making it publicly accessible in approximately two years.” It is perhaps at the comparative or synthetic level, beyond individual projects, that we should seek the greatest interpretive impact. Only after digital datasets are published and researchers start reusing and combining them will the full potential and impact of digital methods be realized.

CONCLUSIONS

As field researchers transition to digital archaeology, they face a number of choices. They must decide the extent to which they want to go digital, whether to pursue mass-market, generalized, or bespoke solutions, and how involved they want to be in software development—bearing in mind that archaeological recording is complex, heterogeneous, and idiosyncratic enough to require significant devel-

opment, regardless of the particular approach (cf. Kansa and Bissel 2010). On one hand, giving developers sufficiently specific instructions, and making implicit knowledge explicit, is time-consuming, tedious, and prone to failure (Segal 2005). On the other, sticking with paper minimizes upfront time investments, at the cost of extensive digitization, data cleansing, and error correction later (Roberts 2011: 147, cited in Huggett 2012: 542). “Just doing it yourself” with commercial software has a certain attraction, but it requires significant compromises because no mass-market software package was built with field archaeology in mind. It also hides, but does not eliminate, much of the effort of scoping, development, and testing, an obfuscation that may lead to significant technical debt and expensive maintenance later (Kruchten *et al.* 2012). Bespoke applications, while capable of producing good outcomes, are expensive to build and difficult to sustain.

The authors of this paper believe that FAIMS strikes a good balance between the re-deployability of general-purpose database software and the domain- and project-specific capability of bespoke applications. Software co-development in a generalized framework like FAIMS, involving a genuine partnership between archaeologists and technologists, is a difficult but productive process that can yield systems that are effective and fit-to-purpose. Archaeologists know their particular projects and where they are likely to be improved by technological intervention, but not always what can be achieved within a reasonable time and cost. Technologists know the capabilities of their software, and, in cases like the FAIMS project, they have accumulated experience across many deployments, including both successes and mistakes. FAIMS 2.0, released in November 2014 is itself an example of co-development as it benefited enormously from the three projects discussed in this paper.

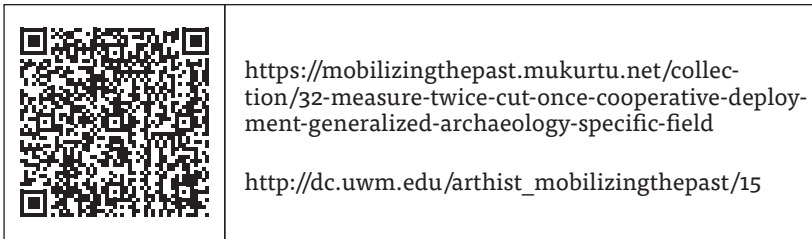
In this context, our case studies revealed a number of consistent themes: (1) moving to digital recording requires an up-front investment of time and resources balanced by a payoff of clean digital data later in the project lifecycle, (2) co-development helps archaeologists and technologists make appropriate decisions to balance features, reliability, and performance, and (3) higher quantity, quality, and availability of digitally-born data is a welcome immediate benefit to the (oft-painful) transition to digital workflow, ahead of potential long-term benefits, like more rigorous analyses and dissemination of

comprehensive digital datasets, which may eventually revolutionize interpretations.

The case studies presented here offer lessons applicable to any field software development project, including customisation of commercial software or development of bespoke applications. Time invested up-front during development pays off with time saved digitizing and cleansing data. Define your requirements and plan carefully, but expect some miscommunications that will only be resolved through iterative testing and development. Leave time for iterating. Leave time for testing. Test early and often. Do not overemphasize features at the expense of performance, testing, and bug fixing. Test *all* hardware and software again under authentic conditions. Ensure field researchers have excellent in-field support. Developing software that is fit-for-purpose is hard, but the benefits of doing it right are worth it.

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REFERENCES

- Baird, D., A. Fairbairn, L. Martin, and C. Middleton. 2012. "The Boncuklu Project: The Origins of Sedentism, Cultivation and Herding in Central Anatolia," in M. Özdoğan, N. Başgelen, and P. Kuniholm, eds., *The Neolithic in Turkey: New Excavations and New Research*. Istanbul: Archaeology & Art Publications, 219–244.
- FileMaker Inc. 2015. "FileMaker Go for iPad & iPhone." <https://www.filemaker.com/au/products/filemaker-go/>
- Fisher, C., M. Terras, and C. Warwick. 2010. "Integrating New Technologies into Established Systems: A Case Study from Roman Silchester," in B. Frischer, J. W. Crawford, D. Koller, eds., *Making History Interactive: Computer Applications and Quantitative Methods in Archaeology (CAA). Proceedings of the 37th International Conference, Williamsburg, Virginia, United States of America, March 22–26, 2009*, <http://discovery.ucl.ac.uk/1324501/1/1324501.pdf>
- Huggett, J. 2012. "Lost in Information? Ways of Knowing and Modes of Representation in e-Archaeology," *World Archaeology* 44: 538–552.
- Kansa, E. C., and A. Bissell. 2010. "Web Syndication Approaches for Sharing Primary Data in 'Small Science' Domains," *Data Science Journal* 9: 42–53.
- Kitchenham, B., S. L. Pfleeger, B. Mccoll, and S. Eagan. 2002. "An Empirical Study of Maintenance and Development Estimation Accuracy," *Journal of Systems and Software* 64.1: 57–77.
- Kruchten, P., R. L. Nord, and I. Ozkaya. 2012. "Technical Debt: From Metaphor to Theory and Practice." *IEEE software* 29 (6): 18–21, doi:10.1109/MS.2012.167.
- Limp, W. F. 2011. "Web 2.0 and beyond, or on the Web, Nobody Knows You're an Archaeologist," in E. C. Kansa, S. W. Kansa, E. Watrall, eds., *Archaeology 2.0: New Tools for Communication and*

- Collaboration*. Los Angeles: Cotsen Institute of Archaeology Press, 265–280.
- Marean, C. W. 2010. "Introduction to the Special Issue: The Middle Stone Age at Pinnacle Point Site 13B, a Coastal Cave near Mossel Bay (Western Cape Province, South Africa)," *Journal of Human Evolution* 59: 231–233.
- Might, M. 2015. "The CRAPL: An Academic-Strength Open Source License." <http://matt.might.net/articles/crapl/>
- Popp, K. M., ed. 2015. *Best Practices for Commercial Use of Open Source Software*. Norderstedt: Norderstedt Books on Demand.
- Raymond, E. S. 2001. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. Rev. ed. Beijing: O'Reilly.
- Roberts, J. 2011. *An Anthropological Study of War Crimes against Children in Kosovo and Bosnia-Herzegovina in the 1990s*. Ph.D. dissertation, Glasgow University, <http://theses.gla.ac.uk/2562/>
- Ross, S., B. Ballsun-Stanton, A. Sobotkova, and P. Crook. 2015. "Building the Bazaar: Enhancing Archaeological Field Recording through an Open-Source Approach," in A. T. Wilson and B. Edwards, eds., *Open Source Archaeology: Ethics and Practice*. Warsaw: De Gruyter Open, 111–129.
- Ross, S., A. Sobotkova, B. Ballsun-Stanton, and P. Crook. 2013. "Creating eResearch Tools for Archaeologists: The Federated Archaeological Information Management Systems Project," *Australian Archaeology* 77: 107–119.
- Runyon, J. 2012. "An Unexpected Ass Kicking." *Impossible*, <http://impossiblehq.com/an-unexpected-ass-kicking/>
- Segal, J. 2005. "When Software Engineers Met Research Scientists: A Case Study," *Empirical Software Engineering* 10: 517–536.
- Sobotkova, A., B. Ballsun-Stanton, S. Ross, and P. Crook. 2015. "Arbitrary Offline Data Capture on All of Your Androids: The FAIMS Mobile Platform," in A. Traviglia, ed., *Across Space and Time: Papers from the 41st Conference on Computer Applications and Quantitative Methods in Archaeology, Perth, 25–28 March 2013*. Amsterdam: Amsterdam University Press, 80–88.
- Sun, Q. 2012. "The Scientific Software Developer in Academia." *Software Sustainability Institute*, <http://www.software.ac.uk/blog/2012-05-01-scientific-software-developer-academia>

- Thompson, J. C., A. Mackay, D. K. Wright, M. Welling, A. Greaves, E. Gomani-Chindebvu, and D. Simengwa. 2015. "Renewed Investigations into the Middle Stone Age of Northern Malawi," *Quaternary International* 270: 129–39.
- VanValkenburgh, P. 2012. *Building Subjects: Landscapes of Forced Resettlement in the Zaña and Chamán Valleys, Peru, 16th–17th Centuries c.E.* Ph.D. dissertation, Harvard University.

