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Workspace: 20 years Retrospective and Prospective

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Abstract:

This paper summarises the development of CSIRO's Workspace, a scientific workflow and application development framework, over the last 20 years and provides some "crystal ball gazing" on what the next 20 years may hold. The initial driver for the development of Workspace was the desire from the Computational Modelling Group (CMG) to commercialise their world leading particle modelling software. A key usage case for Workspace is in supporting commercialisation of research IP by providing low-cost pathways for application development based on extensive re-use of operations and connection to third party components. The Global Innovation Index shows that Australia lags other countries in "research translation" with significant amounts of research IP being stranded (meaning it has no viable commercial pathway to external usage). This paper includes some elaboration on both local and large-scale factors impacting the innovation system and Workspace's role in supporting commercialisation of research IP by enabling creation of novel, distinctive and high value scientific application software that can be licensed or sold.

The initial Workspace prototype was completed in 2005 with refinement and internal use over the next decade leading to a mature software platform which was made generally available in 2014. Workspace-based applications of increasing sophistication have been developed over the next decade. Figure 1 shows a simple schematic of how individual operations link to form a simple workflow which when combined enable complex workflows hierarchically increasing in scale to complete (using UI controlled) applications (with several indicated by the logos in the bottom right corner).

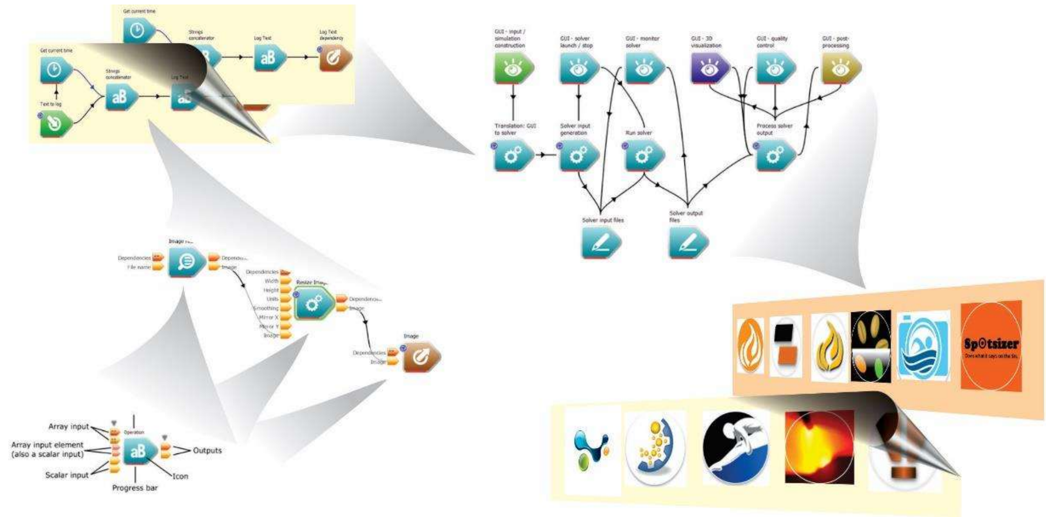

Figure 1: Linkage of operations (bottom left) to form simple workflows (top left) which when linked and nested form complex workflows (top right) and finally to workflow based applications (bottom right).

Looking forward, we discuss key trends affecting workflow systems including Artificial Intelligence, further enhancing support for IP commercialisation and new areas of user interaction, for example visualisation.

Keywords: *IP Commercialisation, Stranded IP, Workspace, workflows, Computational Modelling*.

1. INTRODUCTION

Workspace is a scientific workflow and application development framework that has been under development by the Computational Modelling Group (CMG) at CSIRO since 2005 (Cleary et. al. 2020, Watkins et. al. 2017, Cleary et. al. 2015, Workspace 2014). The preceding statement invites a few pertinent questions: What was the motivation(s) for starting the development of Workspace 20 years ago and do these, or similar/evolving, motivations still exist? How successful has Workspace been at addressing these motivation(s)? Why is Workspace still under development after more than 20 years (and is this a sign of success or failure)? Will Workspace still be under development in 20 more years (and, again, is this a sign of success or failure)? Clearly there are many lenses through which these questions can be viewed. There is our specific motivation and journey to take our Group's IP from research to commercialisation. There is a big picture requirement of moving general research IP to real world impact - and there is the related issue of avoiding “Stranded IP” (Cleary et. al. 2020, Cleary et. al. 2019).

2. BACKGROUND

2.1. The little picture problem of CMG research translation

In 2001, the CMG had (and still has) a leadership position in particle modelling worldwide. CMG needed and wanted to commercialise internal particle based modelling IP/software. These are written in Fortran 90 and executed as standalone applications. As is common with many research codebases, there was no formal or regular testing process, no software engineering expertise and no formal software development processes. So how was CMG going to commercialise their IP?

The traditional approach to creating commercial software (as used by numerous commercial software companies) was not very suitable for the task at hand. Building and maintaining such software products has a significant upfront and ongoing cost and thus this traditional approach often requires “economy of scale”, that is it often requires many users over a long period of time for the process to be economically viable. This forces a larger scope for the software so that it can be used on many problems to capture a sufficient economically viable user base (Cleary, et. al 2020, Cleary et. al. 2019).

On the other hand, a research approach to creating software would include aspects such as using leading edge (or rather bleeding edge) specialised methods which would therefore have a relatively small market size. Research software is usually not written to a sufficient quality level for generalised external use and adoption and is usually not user-friendly or easy to understand. With research software it is often not economically viable to use a traditional software development business model. All of these constraints can lead to significant valuable IP being stranded (or not exploitable) from a commercialisation perspective (Cleary, et. al 2020, Cleary et. al. 2019).

2.2. The big picture problem of CMG research translation

At this point one may wonder if the issues facing the CMG when attempting to commercialise their IP were unique and just a result of their internal process and choices or if the issues were systematic of research software within Australia. The Global Innovation Index (GII) (World Intellectual Property Organization (WIPO) (2024), Cornell University, INSEAD, and WIPO, 2017) is a regular comprehensive global evaluation of absolute and relative innovation performance. Australian innovation performance was ranked 23 (out of 133 countries in 2024 and out of 127 countries in 2017). This shows that overall Australia’s rankings remain consistent and poor over time. In 2024 Australia’s Innovation input to output performance was labelled as “Inefficient”, Australian Innovation Input was ranked higher at 18 but output was only ranked 30. In 2017 Innovation input was ranked much higher at 12 but output was only ranked 30. The “Innovation Efficiency Ratio” (the ratio of the Innovation Output to Input sub-indices) in 2017 was 0.6 which ranked 76 (out of 127 countries surveyed). It was noted in 2024 that “However, certain economies, including Australia (23rd), ..., find it harder to translate inputs into outputs.” Research translation is intrinsically difficult everywhere, but the data shows that it is particularly difficult in Australia. These rankings present a consistent long-term picture of relatively high levels of investment in research but with relatively low levels of translation into economic outputs. It is useful to observe that in 2017 Australia ranked 9th in terms of publication outputs and 10th for Citable Document H-index. However, in contrast its ranking for “ICT services exports” was only 77 in 2024 and 89 in 2017.

3. CSIRO WORKSPACE

To address these challenges and enable the commercialisation of their IP, around 2002 the CMG started to develop a reusable scientific software platform; eventually this platform was officially named Workspace.

3.1. Workspace Timeline

A brief timeline for the development and utilisation of Workspace begins between 2002-2005 when a number of prototypes and evaluations were undertaken within CMG and with some external collaborators. Around 2005 an original concept/design was formulated and between 2005 until 2008 there was initial development and usage within the CMG. Between 2008 and 2009 a growing number of Groups within our Research Unit appreciated the need for having a low-cost commercialisation pathway and this led to our Research Unit (now named Data61) funding support. Between 2010-2016 CSIRO more broadly identified the value of Workspace and the opportunities it could enable for the organisation and provided development support via Computational and Simulation Sciences Transformation Capability Platform and eResearch Initiatives. The first public Workspace based application appeared in 2014 (Whan, A., et.al 2014). In October 2014 Workspace was made available via a public launch through CSIRO Data Access Portal (DAP). Workspace updates are regularly made available in the DAP (https://doi.org/10.25919/reyt-xn80) and is used in active projects for research and product delivery by CMG, wider CSIRO groups and external organisations.

3.2. Workspace Design Goals

Workspace provides a number of advantages when developing scientific workflows or applications. While there are too many capabilities to specifically enumerate here, we list a few to provide an overview of Workspace's functionality. These include: 1) support for commercialisation, 2) continuous execution mode with minimal execution paths, 3) remote and distributed execution modes, and 4) advanced interactive visualisation (see these for more specifics: Cleary et al. 2020, Watkins et. al. 2017, Cleary et al. 2015).

3.3. Conceptual framework template for a Workspace based application

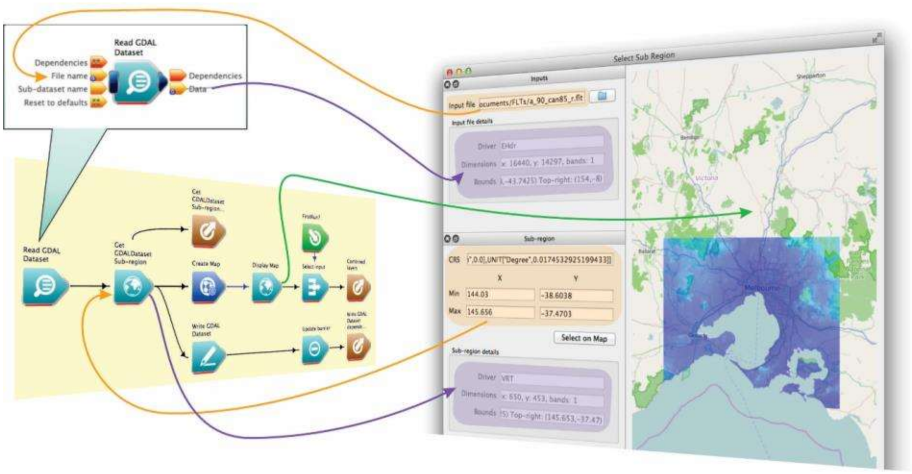

Figure 2. Connection between underlying workflow to an application UI layer.

Figure 2 provides an intuitive visualisation of the relationship between Workspace workflows and an application User Interface (UI) – showing the connections and relationship between them.

4. WORKSPACE BASED APPLICATIONS

This section details some of the publicly cited Workspace based applications[1]. One interesting point is that the commercial-in-confidence applications often have longer lifespans than publicly available applications, that is commercial-in-confidence applications tend to be based on highly differentiated underlying IP so continue creating value for both scientists and customers whereas purely research based or open-source applications often tend to be great demonstrators whose IP is emulated.

4.1. ArcWeld

ArcWeld (Murphy et. al. 2023, Thomas, et. al. 2019, Murphy et. al. 2017), a specialised package for modelling arc welding, followed what is a typical research development pattern. An existing research-grade solver used to control a complex simulation of physical processes was required for use by a customer, in this case General Motors, but the expert-level knowledge of both the software and underlying science was prohibitive for a shop-floor engineer. This complex solver was wrapped up using Workspace components (mostly pre-existing),

[1] It should be noted that that there are several commercial-in-confidence applications, (after all that was the driver for developing Workspace initially), however, these commercial-in-confidence applications cannot be detailed here.

providing a simplified and intuitive GUI for use by technicians. Following delivery of ArcWeld, further extensions to the software were implemented to produce a second application, WAAM (Wire Arc Additive Manufacturing), a jointly driven, non-commercial project by the Rail Manufacturing Cooperative Research Centre (RMCRC) and CRRC Qishuyan Locomotive & Rolling Stock Technology Research Institute Co., Ltd., Qishuyan, China (CRRC QSYRI). Because of the use of the Workspace framework, the production time of this second similar software package was even further reduced when compared to starting from scratch due to extremely high levels of re-use and the ease of evolution of the workflows and UI.

4.2. Digital Human/DiveMechanic/ErgoMechanic

CSIRO's Digital Human (DH) Initiative provides simulations of common activities such as eating and motion with the goal of improving health, performance and safety. One example DH application is Dive Mechanic, a custom 3D software application for modelling elite level diving, in collaboration with Australian Institute of Sport and developed by CSIRO for use by Diving Australia. It was built using the Workspace framework and a CSIRO Data61 developed human biomechanics motion engine wrapped in a custom application allowing diver technique to be predicted in real-time and enabling interactive modification of technique by poolside coaches (Cohen, et. al. 2017). A related application re-using much of the workflow framework and components called ErgoMechanic (Harrison, et. al. 2025, Cohen et. al 2021) has been developed for assessing human ergonomics and movement.

4.3. GrainScan

Certain characteristics of agricultural grains are key indicators for cereal breeding and research. Some characteristics have a high influence factor on the grain's productivity, such as colour, shape and size, but are difficult to accurately measure while other characteristics are easier to measure (such as weight) but are less useful in determining outcomes. The GrainScan application was developed to capture images of grains from scanners and then to accurately measure characteristics, such as their colour, shape and size. (Whan, et. al. 2014). GrainScan was the first CSIRO application publicly released by CSIRO and was developed by the Agriculture & Food Research Unit with assistance from the CMG thus demonstrating the usability of Workspace by non-expert developers and, as with ArcWeld, was not related to the core IP of the CMG.

4.4. Heliosim

Heliosim (Potter, et. al. 2018, Potter, et. al. 2017) integrates a computational model for the optimisation and simulation of a central receiver Concentrating Solar Thermal (CST) power plant inside a Workspace-based application. CST installations utilise an arrangement of heliostats (reflective surfaces) which can be independently aligned to concentrate sunlight onto a centrally located receiver (a heat transfer device). The receiver can have different implementations, such as a falling curtain of solid particles or banks of pipes containing a fluid (e.g. molten salt.) Unlike other solar energy harvesting solutions (e.g. photovoltaic solar panels), the thermal energy can then be stored and used on-demand to drive electric turbines or industrial chemical processes after the sun has set. The computational model consists of a GPU-accelerated ray tracing model for simulating solar and thermal radiation transfer, and a finite volume model for simulating heat transfer processes within the receiver. This model can be used to both: 1) optimise the system design given specific requirements (e.g. nameplate capacity, location), and 2) evaluate the performance of a fully specified system design. The C++ API for Heliosim has been in development and usage at CSIRO for more than 18 years. After almost two decades of internal use and development within CSIRO, the Heliosim software suite has recently been commercially licensed.

4.5. PipeTwin

The PipeTwin application is a real-time monitoring and control system for use in suspension pipelines. The transport of mineral suspensions in pipelines is very complex due to the multiphase nature of suspension flow. However, such transport systems are central to many industrial processing operations, particularly in the mining section, PipeTwin is an example of a "Digital Twin" application, where integration with live instrumentation in the field provides the real time status of the system, offers a powerful means to successfully address the challenges of managing a suspension pipeline by enabling real-time control of the system from the embedded model. PipeTwin is a flexible and scalable framework, which integrates real-time data from a diverse array of pipeline instruments (including rheometers, pressure transmitters, flowmeters and density meters) into digital twins (Xie, et. al. 2025).

5. MIXED REALITY LAB

A Digital Twin can be defined as being a real-world process, a virtual model of that process and the connections that allow communications between both. Thus, the real-world process informs the model and the model controls the process. As part of the recent development of Workspace to deal with Digital Twins, a Mixed Reality Lab (MRL) (Watkins, et al 2023, Hetherton, et. al. 2019) was created at CSIRO's Clayton site. The MRL can be described as an "Industry 4.0 testbed". In the initial development phase of Workspace, more than a decade before, the need for supporting Digital Twins (e.g. Industry 4.0) was not an identified goal. However, the functionality of the Workspace platform served as a strategic advantage and enabler that allowed it to quickly and adaptively meet the needs of this new area.

6. THE NEXT 20 YEARS

While future projections remain speculative due to unpredictable technologies and shifting research priorities, several long-term trends are evident and discussed next.

6.1. Artificial Intelligence

As use of agentic AI (Artificial Intelligence) becomes standard practice in software development and the use of AI to drive aspects of the scientific process increase, Workspace's integration with large language models represents both a strategic necessity for platform relevance and a natural evolution of its scientific computing and commercialisation goals. Equally significant is the opportunity for AI to accelerate Workspace's own development and maintenance to expand the platform more effectively.

6.1.1. AI and natural language creation and execution of workflows

Early prototyping through technologies like Model Context Protocol (MCP) demonstrates potential pathways for agentic AI integration with Workspace, enabling scientists to construct, execute and analyse results for complex workflows assisted by natural language instructions. These explorations point toward transforming many aspects of traditional UI-driven workflow development into conversational interfaces where researchers can describe their scientific requirements and have AI agents automatically generate and interact with tailored workflows. This natural language approach could address barriers to Workspace adoption across diverse scientific domains. By enabling researchers to express their needs in plain language, AI agents will be able to leverage the Workspace ecosystem capabilities to automatically configure and explore scientific workflows.

6.1.2. Workspace AI capabilities in end-user applications

With Workspace's foundational principle of building reusable capabilities, the AI integration patterns developed for the core platform should be designed to be inheritable by end-user applications built with the framework. The architectural patterns established through Workspace's MCP integration, RPC-enabled architecture, and enhanced Python bindings are expected to be able to create extensible capabilities that domain-specific applications can leverage without requiring teams to develop complex AI integrations from scratch. This extension mechanism should allow specialised scientific applications developed with Workspace to inherit conversational interfaces, automated parameter optimisation, intelligent documentation generation, and multimodal analysis capabilities as standard platform features.

6.1.3. AI support for Workspace onboarding, capability discovery and troubleshooting

The traditional model of Workspace training through static documentation and in-person workshops has faced scalability challenges as the platform evolves and user communities grow across diverse scientific domains. AI-powered onboarding systems could transform this approach by providing personalised, interactive learning experiences that adapt to users' specific scientific backgrounds and requirements. Large language models drawing on Workspace's documentation corpus, tutorial materials, and accumulated expert knowledge could deliver contextual guidance more effectively than existing human instruction while being available on-demand and tailored to individual learning paths.

6.2. Workspace as a piece in larger scientific processes

The team is developing enhanced Python bindings for Workspace via Pybind11, building on earlier integration concepts while enabling significantly more powerful and flexible interactions. This architectural inversion - from Workspace containing Python to Python containing Workspace - leverages Python's dominant role in modern research computing and AI, reduces barriers to entry compared to C++ development for many of Workspace's users, and enables flexible hybrid approaches where interactive visual workflows can be created, modified, and executed programmatically within an interpretive environment or Python-based web services.

6.3. Enhanced commercialisation through multi-level reusability

The development process for new components for in-house modelling and simulation software frequently involves either writing code from scratch or copy-paste-modification of already existent code for similar components. These components can be quite different from an application perspective but have much commonality from a software perspective. Thomas et al. (2023) explored how the use of an architecture based on a workflow system such as Workspace along with generic higher-level components built in this system can foster high levels of re-use. This can significantly accelerate development and reduce its cost, while improving maintainability, software quality and robustness. This enables application designs with simple, custom user interfaces capturing just the capabilities that are needed and presented in a form that is most intuitive to the software users, in contrast to a more traditional design based around a single monolithic interface with substantial complexity. This leads to having custom software products for each domain or sub-domain raising the question of how to easily and efficiently construct families of related software products from a common IP pool but with different custom interfaces.

6.4. Advanced visualisation, error detection and results interpretation support systems

Visualisation of flow and structure for very large-scale dynamic simulations is challenging because of the scale and complexity of the data. This is particularly true for data generated by particle-based simulations because state data generated by discrete methods is inherently more variable than that from continuum methods (which by its method of construction is smoother and more continuous). Traditionally, visualisation is guided by initial visual inspection of the data. Once discrete generated simulation data exceeds around 5 million points, the size of the points becomes sub-pixel and fine structure (such as particle size and shape and often even many of the smaller particles) are no longer observable in a render of the full scene. So, the user can either view the full scene and be unable to observe much of the finer structure or must look at close-up views to see the structure but without any guidance as to where to look. At 100 million particles and above, these challenges become extreme with several levels of zoom required from the full-scale scene to even be able to distinguish individual discrete points. In principle, this would seem an ideal application for AI. However, since flow structure contained in each data set is specific to that particular set of data, pre-training is neither feasible nor overly useful. So, self-training or bootstrapping AI approaches are necessary. However, these methods are much less mature and their use in such circumstances is still regarded as challenging. For error detection, there is some possibility that known classes of failure for specific numerical methods may be amenable to some form of training for the AI identification system.

6.5. Level-of-detail control for large point clouds

Large point-cloud (1million+ points) visualisation requires specific capabilities to enable varying Levels-of-Detail (LODs) for different view distances / perspectives, as rendering the entire dataset is very computationally expensive, which makes user interaction very difficult. Workspace provides capabilities to efficiently decompose point clouds into manageable hierarchical structures, optionally stored offline, where patches can be streamed into graphics memory for visualisation as needed. The specific methods used for effectively decomposing the dataset and selecting the most appropriate LOD for each patch will vary depending on the structure of the point cloud, as well as the intended use case (e.g. simulation vs. environmental scan) (Hetherton et al. 2025). Workspace provides a flexible visualisation and pre/post-processing framework for domain-specific workflows to cater to these application-specific challenges.

7. CONCLUSION

The initial motivation for creating Workspace was to assist with the commercialisation of the CMG's world leading particle modelling IP. In this regard Workspace has been extremely successful – and over several years and several iterations. The development of Workspace was a multi-year effort and although originally started within the CMG eventually it required support and funding from across CSIRO. In return for this investment, direct benefits have been gained by multiple CSIRO Research Units as demonstrated by the growing number of Workspace-based applications (either in-house, commercial and/or public).

There have been other benefits discovered along the journey, having a platform such as Workspace allowed the CMG to move into other areas such as "Digital Twins" and the MRL much faster and easier than would have been possible if the Group had to develop several systems from scratch. Workspace does not seek to reinvent the wheel either; overall Workspace will continue to evolve to bring new technologies into the Workspace platform. This reuse model has been showed by the number of plugins developed for external technologies. It is envisaged that the adoption of AI within Workspace will lead to both more adoption of Workspace and more usage of AI by CMG scientists.

REFERENCES

Cohen, R. C. Z.; Harrison, S. M. (2021) "Ergomechanic: A markerless motion capture and ergonomic assessment tool developed using the Workspace workflow engine." In: 24th Int. Congress on Modelling and Simulation (MODSIM2021); 05 to end of 10 Dec 2021; Sydney, NSW, Australia.

Cohen, R. C. Z., Harrison, S. M., Cleary, P. W, and Bolger, M. (2017) "Dive Mechanic: Bringing 3D virtual experimentation to elite level diving using the Workspace workflow engine", 22nd Int. Congress on Modelling and Simulation, Hobart, Tasmania, Australia, 3 to 8 December 2017,

Cleary, P. W., Thomas, D., Hetherton, L., Bolger, M., Hilton, J. E., and Watkins, D., (2020) "Workspace: a workflow platform for supporting development and deployment of modelling and simulation", revised for: Mathematics and Computers in Simulation, (2020). 175, 25-61, ISSN 0378-4754

Cleary, P.W., Hetherton, L., Thomas, D.G., Bolger, M. and Watkins, D. (2019), "Translation of stranded IP to commercialisable software applications using Workspace", 23rd Int. Congress on Modelling and Simulation, Canberra, ACT, Australia, 1 to 6 December 2019,

Cleary, P.W., Thomas, D., Bolger, M., Hetherton, L., Rucinski, C., and Watkins, D., (2015) "Using Workspace to automate workflow processes for modelling and simulation in engineering", 21st Int. Congress on Modelling and Simulation, Gold Coast, Australia, 29 Nov to 4 Dec 2015

Cornell University, INSEAD, and WIPO, (2017), The Global Innovation Index 2017: Innovation Feeding the World, Ithaca, Fontainebleau, and Geneva. ISSN 2263-3693. ISBN 979-10-95870-04-3.

Cornell University, INSEAD, and WIPO (2019), The Global Innovation Index 2019: Creating Healthy Lives—The Future of Medical Innovation, Ithaca, Fontainebleau, and Geneva. ISSN 2263-369. ISBN 97910-95870-14-2.

Harrison, S., Cohen, R.. C. Z., O'Hanlon, J., Cece, T., Fisher, N., Thrall, Pete. "Proof of concept system evaluation of Ergomechanic for real-time and non-invasive estimation of workplace body load exposure." Int. Journal of Occupational Safety and Ergonomics. 2025; 0(0):1-13.

Hetherton, L., Bolger, M., Zhang, Z., Oakes, N., Watkins, D. and Cleary, P.W (2019), "Workspace for Industry 4.0", 23rd Int. Congress on Modelling and Simulation, Canberra, ACT, Australia, 1 to 6 December 2019

Murphy, A. B., Thomas, D. G., Chen, F. F., Xiang, J. and Feng, Y. (2023) 'Transforming a computational model from a research tool to a software product: A case study from arc welding research', Software 2 258–275 (2023)

Murphy, A. B., Thomas, D. G. (2017), "A computational model of arc welding – from a research tool to a software product", 22nd Int. Congress on Modelling and Simulation (MODSIM) 2017,

Office of Chief Economist, (2017), (https://web.archive.org.au/awa/20150720215215mp_/http://pandora.nla.gov.au/pan/40787/20150720-0002/apo.org.au/files/Resource/industry-monitor-2015.pdf?nid=55871&file=http://apo.org.au/files/Resource/industry-monitor-2015.pdf)

Potter, D.F.., Kim, J-S., Khassapov, A., Pascual, R., Hetherton, L., Zhang, Z. (2018); "Heliosim: An integrated model for the optimisation and simulation of central receiver CSP facilities." AIP Conf. Proc. 8 November 2018; 2033 (1): 210011.

Potter, D.F., Khassapov, A., Pascual, R., Hetherton, L., and Zhang, Z. (2017) "Heliosim: A Workspace-driven application for the optimisation of solar thermal power plants extended abstract", 22nd Int. Congress on Modelling and Simulation (MODSIM) 201.

Thomas, D. G., Cummins S. J., and Cleary, P. W., (2023), How to create and support families of deliverable software products from a common IP pool with high levels of software reuse in a workflow platform, MODSIM2023, July 2023, pp. 835–941. ISBN: 978-0-9872143-0-0.

Thomas, D., Murphy, A.B., Chen, F. F., Xiang, J., Feng, Y., (2019) ArcWeld: A case study of the extensibility of software applications built using Workspace architecture presented at 23rd Int. Congress on Modelling and Simulation (MODSIM) 2019.

Watkins, D., Bolger, M. and Zhang, Z. (2023), "Workspace and the Mixed Reality Lab: Where scientific workflows meet Industry 4.0", 25th Int. Congress on Modelling and Simulation, Darwin, NT, Australia, 9 to 14 July. https://doi.org/10.36334/modsim.2023.watkins

Watkins, D., Thomas, D., Hetherton, L., Bolger, M., Cleary P.W. (2017), "Workspace - a Scientific Workflow System for enabling Research Impact" 22nd Int. Congress on Modelling and Simulation, Hobart, Tasmania, Australia, 3 to 8 December 2017. https://mssanz.org.au/modsim2017/C3/watkins.pdf

Whan, A., Smith, A., Cavanagh, C., Ral, J.-P., Shaw, L., Howitt, C., and Bischof L. (2014) "GrainScan: a low cost, fast method for grain size and colour measurements." Plant Methods, 10(1):23, 2014

Workspace (2014). DOI: http://dx.doi.org/10.4225/08/54D03170101B7

World Intellectual Property Organization (WIPO) (2024). Global Innovation Index 2024: Unlocking the Promise of Social Entrepreneurship 10.34667/tind.50062

Xie, P., Zheng, E., Nguyen, D., Chryss, A., and Hetherton, L. (2025) "PipeTwin: A Scalable Framework for Digital Twin Deployment in Mineral Suspension Pipelines" submitted to MODSIM 2025

