Taichi: An Open-Source Computer Graphics Library

YUANMING HU, MIT CSAIL

An ideal software system in computer graphics should be a combination of innovative ideas, solid software engineering and rapid development. However, in reality these requirements are seldom met simultaneously. In this paper, we present early results on an open-source library named Taichi (http://taichi.graphics) which alleviates this practical issue by providing an accessible, portable, extensible, and high-performance infrastructure that is reusable and tailored for computer graphics. As a case study, we share our experience in building a novel physical simulation system using Taichi.

1 WHY NEW LIBRARY FOR COMPUTER GRAPHICS?

Computer graphics research has high standards on novelty and quality, which lead to a trade-off between rapid prototyping and good software engineering. The former allows researchers to code quickly but inevitably leads to defects such as unsatisfactory performance, poor portability and maintainability. As a result, many projects are neither reused nor open-sourced, stopping other people from experimenting, reproducing, and developing based on prior art. The latter results in reusable codes for future projects, but slows down research progress due to low-level engineering such as infrastructure building. Admittedly, for a researcher too much low-level engineering may become an obstacle for high-level thinking.

Existing open-source projects are focused on certain functionality, like rendering (e.g. Mitsuba [Jakob 2010], PBRT [Pharr et al. 2016], Lightmetrica [Otsu 2015], POV-Ray [Buck and Collins 2004], etc.), geometry processing (libIGL [Jacobson et al. 2013], MeshLab [Cignoni et al. 2008], CGAL [Fabri and Pion 2009], etc.), simulation (Bullet [Coumans et al. 2013], ODE [Smith et al. 2005], ArcSim [Narain et al. 2004], VegaFEM [Sin et al. 2013], MantaFlow [Thueray and Pfaff 2017], Box2D [Catto 2011], PhysBAM [Dubey et al. 2011], etc.).

The aforementioned libraries have proven successful in their own applications. However, though some projects can more or less reuse these frameworks, building prototypical systems from scratch is often necessary when modifying these libraries becomes even more expensive than starting over. Taichi is designed to be a reusable infrastructure for the latter situation, by providing abstractions at different levels from vector/matrix arithmetics to scene configuration and scripting. Compared with existing reusable components such as Boost or Eigen, Taichi is tailored for computer graphics. The domain-specific design has many benefits over those general frameworks, as illustrated in Fig. 2 with a concrete example.

![Fig. 1. Results simulated and rendered using Taichi.](image)

![Fig. 2. Why do we need a tool tailored for graphics? Consider 3D matrix-vector multiplication as an example. In Eigen single-precision 3D vectors are stored compactly using 12 bytes. Compared with 16-byte-aligned storage, this scheme saves some space, but offers unsatisfactory performance since additional permutation in SIMD registers is needed for vectorized computation. In graphics we care more about throughput and latency instead of space, so Taichi’s vector system is designed in the latter way and is 1.8 – 2.3x faster.](image)
2 DESIGN GOALS

Accessibility. Taichi is open-source and easy-to-use by design. We avoid unnecessary dependencies, especially hard-to-deploy ones such as Boost. Installation can be done simply by executing a python script that automatically installs all dependencies. For beginners, it contains many working demos that showcase how this software should be used at a high level.

Portability. Taichi is cross-platform and supports Linux, OS X and Windows. Our aim is to make every project built on Taichi automatically portable by providing an abstraction of the actual operating systems. This makes open-sourcing projects much easier.

Reusability. Taichi contains common utilities for developing graphics projects. Reusing them can significantly speed up development since the time spent on (re)inventing the wheels is saved.

Extensibility. With a plugin-based design, Taichi allows users to quickly add their own implementations of existing or new interfaces. The implementations ("units") will be automatically registered at program load time and can be instantiated conveniently with a name identifier through the factory.

High-performance. We offer not only efficient (sometimes zero-cost) abstractions at different levels of Taichi, but also performance monitoring tools such as scoped timers and profilers to make performance engineering convenient.

3 COMPONENTS

Here we present some representative components that can be reused for developing new computer graphics systems.

(De)serialization. The serialization system allows marshaling internal data structures in Taichi into bit streams. A typical application is snapshotting. Many computer graphics programs take a long time to execute and it is necessary to take snapshots of current states. In case of run-time error, the program can continue running from the latest snapshot after the bug causing crashing is repaired. Other use cases include inter-program communication when there is no shared memory. Our serialization library is header-only and can be easily integrated into other projects for reading the serialized Taichi data.

Logging and Formatting. Appropriate logging is an effective way to diagnose a long-running program. Taichi internally uses spdlog and fmtlib. The former manages logging and the latter is a modern formatting library which unifies string formatting in C++ and Python. It is safer, easier to use and more portable than its alternatives like std::cout and printf.

Profiling. Though there are mature external profiling tools like gprof or Intel VTune, using them needs additional manual operations. Taichi has an integrated scoped profiling system that records the time consumption of each part automatically, simplifying hotspot analysis.

Debugging and Testing. C++ programs do not generate much useful debugging information when it crashes. This makes debugging hard and is the reason why Taichi captures run-time errors and prints stack back-trace. On Linux, it additionally triggers gdb for debugging. Once a task finishes (or crashes), Taichi can send emails to notify the user. Taichi uses Catch2 for testing and we aim to build a high-coverage test suite for the library.

Rendering. Though not designed to compete with existing rendering frameworks, Taichi provides demonstrative implementations of popular rendering algorithms, from basic path tracing to modern ones such as vertex connection and merging [Georgiev et al. 2012]/unified path sampling [Hachisuka et al. 2012] with adaptive Markov chain Monte Carlo [Šik et al. 2016].

Simulation. Taichi is shipped with several physical simulators including APIC [Jiang et al. 2015]/FLIP [Zhu and Bridson 2005] liquid/smoke simulation with a multigrid-preconditioned conjugate gradient (MGPCG) [McAdams et al. 2010] Poisson solver for projection. We will also release a high-performance material point method code, as detailed in section 4.

File IO support. Taichi supports reading and writing of popular file formats for computer graphics, including obj (via tinyobjloader) and ply, jpg, png, bmp, ttf (via stb_image, stb_image_write, stb_truetype), In addition, Taichi wraps common utilities provided by ffmpeg. It can generate mp4 or gif videos from an array of images, either in memory or on disk.

Scripting. Taichi has a hybrid design with a kernel part in C++14 and an easy-to-use interface in Python 3. Such approach decouples inputs like demo set-up from the actual kernel computation code. pybind11 is used for binding C++ interface for Python.

In addition, we built Taichi based on Intel Thread Building Blocks for multithreading. An efficiently vectorized linear algebra library is also developed to suit computer graphics applications better, as mentioned in Figure 2. The Taichi developer team is in charge of maintaining and simplifying the deployment process of all the aforementioned dependencies of Taichi.

4 CASE STUDY: A PHYSICAL SIMULATION PROJECT

So far, we have used Taichi in five research projects. Published ones include [Hu and Fang 2017; Hu et al. 2018]. Here we summarize our experience during the development of the SIGGRAPH 2018 paper "A Moving Least Squares Material Point Method with Displacement Discontinuity and Two-Way Rigid Body Coupling" [Hu et al. 2018], abbreviated as "MLSMPM-CPIC". Taichi is used as the backbone of the simulator development of this project. Visual results are displayed in Figure 3.
Productivity. All features mentioned in the previous section proved useful. In fact, many of them are developed during research projects like this one for productivity and future reusability. For example, the serialization system allows us to periodically save simulation states to disk, and conveniently restart from these snapshots. It is especially important for long-running simulations which can take hours or even days. Performance engineering is guided by the Taichi profiler, which shows a breakdown of time consumption and has led to significantly higher efficiency compared with the previous state-of-the-art [Tampubolon et al. 2017].

Team Scalability. The python scripting system makes our development especially suitable for team working, because the algorithm development (in C++) and experimental validation (via python scripts) are nicely decoupled: for most of the time only one or two core members need to develop the C++ simulation code, and all team members can help conducting experiments without getting involved into low-level details.

In general, the team is satisfied with this infrastructure and has decided to build future projects on it. We believe the user experience will continue to improve as we battle-test it in more projects.

5 FUTURE WORK

Clearly, a lot more engineering efforts are needed to improve Taichi. Detailed documentation and better test coverage are two urgent tasks. Improving and stabilizing the interface design, support for other open-source softwares like Blender are also very meaningful.

ACKNOWLEDGEMENTS

The author would like to thank Toshiya Hachisuka and Seiichi Koshizuka for hosting his internship at the University of Tokyo, where he developed the initial version of Taichi. Chenfanfu Jiang provided helpful suggestions for developing Taichi and supported its adoption in several projects. Other developers, especially Yu Fang, also contributed to Taichi. Some demo scenes are from [Bitterli 2016]. Finally, thank all the open-source software developers for making their achievements freely available to everyone.
Nils Thuerey and Tobias Pfaff. 2017. MantaFlow. (2017). http://mantaflow.com.
Yongning Zhu and Robert Bridson. 2005. Animating sand as a fluid. ACM Transactions on Graphics (TOG) 24, 3 (2005), 965–972.

CHANGE LOG
April 24, 2018: initial version.