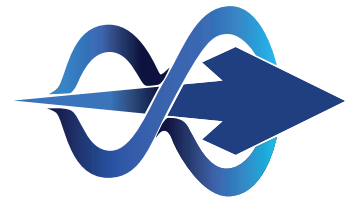


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At PSA, we are committed to constantly innovating through automation and the use of intelligent systems to enhance our operations and competitiveness. We chose to work with MemComputing, Inc. because of the innovative and disruptive nature of their technology. We presented them with a difficult benchmark as a Proof of Concept to determine if their technology could overcome exponential scaling. The MemComputing team was extremely knowledgeable and able to demonstrate their ability to solve this exponential problem in polynomial time. We were quite impressed with the result.

- Liang Ping Ku, PhD
Assistant Vice President
(Optimization and Application Design)
PSA Corporation Limited

Port Logistics Case Study



MemComputing Inc.

Port Logistics

Digital transformation and automation are ushering in a new era of port development and terminal infrastructure that will support better productivity, efficiency and flexibility. Ports are developing, testing and experimenting with automation technology to perform tasks once handled by humans- for example, using artificial intelligence, intelligent workflows, robots, as well as autonomous vehicles and stacking cranes for unloading and loading, and moving cargo containers (depending on the material they are made of and size, the average 20-foot container + cargo weighs 26.5 tons) from ship to ship, ship to stowage, and stowage to rail, truck and air transportation. The technology is seen as one of the most efficient ways to deal with rising shipping traffic and new mega ships that haul more and more containers. Automating a port's activities can bring its logistics up to speed and improve land efficiencies by getting more capacity out of limited port space and real estate while reducing the time ships sit in port and cargo containers sit in storage.





CUSTOMER PROFILE/PSA SINGAPORE TERMINALS

World-class Port Operations

PSA Singapore, operates the world's largest container transshipment hub. PSA's core business in Singapore is transshipment, transferring containers from one vessel to another vessel bound for its final destination. Its terminals at Tanjong Pagar, Keppel, Brani and Pasir Panjang function as one integrated facility, handling large-scale, complex transshipment arrangements efficiently and seamlessly, 24/7.

PSA also operates a multi-purpose terminal (MPT) comprising Pasir Panjang Automobile Terminal and Sembawang Wharves. MPT has the capacity to handle more than a million vehicles annually. In addition, Sembawang Wharves provides a host of port-related logistics solutions.

PSA Marine (Pte Ltd) offers a wide portfolio of services including pilotage, port and terminal towage and ocean transportation services. A leading provider of marine services, PSA Marine commands the largest and most powerful fleet of modern harbor tugs in Asia.

Singapore's strategic location in the heart of Southeast Asia and at the nexus of major shipping routes has made it an important logistic hub and conduit for world trade—giving shippers and carriers flexibility in choosing how to get their goods to market fast. Shippers have access to daily sailings to every major port in the world at this mega hub. Its excellence in port operations has consistently been recognized by the shipping community. In 2018, it won the "Ports and Terminals Award" at the Seatrade Maritime Awards Asia. PSA Singapore handled 36.31 million TEUs of containers in 2018.

The port constantly innovates through automation and the use of intelligent systems to enhance its customers' hubbing operations and competitiveness. Growing ship size and increasing business complexity demand greater efficiency and productivity. To manage this expansion and growth PSA has invested in an award-winning Flow-Through Gate system which clears incoming trucks in 25 seconds, and remotely-controlled semi-automated bridge cranes where each operator can handle up to 6 cranes. Innovation is very much at the core of PSA's DNA where they have implemented a fully-automated yard crane system at Pasir Panjang Terminals 4, 5 and 6, and are testing automated guided vehicles (AGV) for their future container terminals. They are also focusing on optimization techniques and green technologies, so that their business is even more streamlined and sustainable in the long term.

PSA is a leader in e-business solutions in the port industry. Its two award winning applications, PORTNET® and Computer Integrated Terminal Operations System (CITOS®), have given PSA the edge to achieve greater levels of productivity and efficiency. PORTNET®, the world's first nationwide B2B shipping e-community, serves over 10,000 integrated users and facilitates more than 220 million transactions annually. CITOS® coordinates and integrates all aspects of port operations across their container terminals.

Solving Logistics and other Problems with MemComputing

The MemCPU™ Coprocessor technology takes a new approach to computation of complex optimization problems, especially those that are combinatorial in nature, that is different from any method previously taken. This technology is an extreme turbo-booster for virtually any computer, from the slowest laptop to the fastest supercomputer. This computing increase isn't simply ten or one hundred times faster, it is hundreds, thousands, tens of thousands or more times faster depending on the problem. In effect, the harder and more complex the problem, the greater the boost in performance. MemCPU Coprocessors are designed to handle massive and complex mathematical computations in a fraction of the time using a fraction of the resources of today's best in class solutions.

Today's classical (non-quantum) computers are confined when it comes to solving a class of problems categorized as NP-hard and NP-complete. These problems are identified where the computational time and/or memory resources required explode exponentially while the inputs and constraints simply grow sequentially.

In previous benchmarks MemComputing has shown empirical evidence that a non-combinatorial approach using its MemCPU Coprocessor demonstrated the availability of efficient solutions to NP-hard problems. The outstanding performance of our physics-based approach shows advancements in optimization computations.

MemCPU Coprocessors are designed to integrate with current workflow. The software supports integer linear programming problems (ILP), quadratic unconstrained binary optimization problems (QUBO), polynomial unconstrained binary optimization problems (PUBO), Maximum Satisfiability (Max-SAT) and some Satisfiability problems (SAT), with more methodologies and capabilities being added. The software supports direct data exchange as well as file-based data exchange with Mathematical Programming Systems (.mps) and Conjunctive Normal Form (.cnf).





PSA Tests a Nontraditional Solution for Logistics Optimization Problem

PSA's excellence in port operations has consistently been recognized by the shipping community. It's an innovator that is always exploring new options and methodologies to improve its business and its customers' experience. PSA Singapore prides itself as one of the most modern ports in the world, and it's undertaking a 20-year modernization and expansion project to ensure that it will be able to keep up with the increasing demand and competitiveness for shipping in this important Asian gateway hub.

When PSA learned about MemComputing's disruptive coprocessor technology, they were naturally skeptical of the claims. However, they were intrigued enough that they wanted to put MemComputing to the test. To do this, PSA identified a benchmark that is known to be NP-Hard and is representative of real-world logistics problems that a port may face. Specific details regarding the exact problem remain confidential based on an agreement between the companies.

PSA presented MemComputing with two data sets for the problem where the second data set was a little more than 3 times larger than the first data set. Being an NP-Hard problem, similar to the color problem described in the aside, the compute time for this problem grows exponentially for each new input variable added using current methods. What we did know was that the best in class solution for the first data set exceeded 70 hours and scaled exponentially. Mathematically, the time required to calculate an exponential problem can be represented by $f(x) = \alpha 2^{\beta x}$. (See note) Thus, adding one more variable increases the compute time $f(x + 1) = \alpha 2^{\beta(x+1)}$. Given the observed scaling and that the first problem takes 70 hours, the number of hours that a problem that is 3 times as big would take beyond the age of the universe to compute (@ 13 billion years).

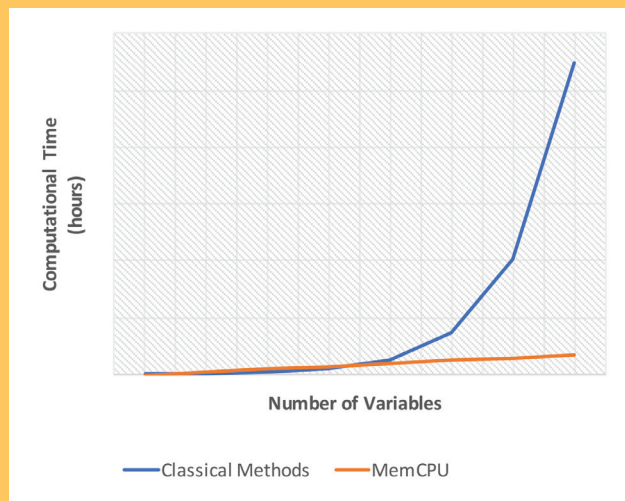
NP-Hard problems refer to a class of problems that grow exponentially in complexity with the addition of each new input variable. These problems are often combinatorial, where the combination of possible solutions or permutations grows at an increasing rate for each additional input. Consider a simple problem with colors where you can have 100% of each color or you can mix them in equal amounts. If you start with a single color, green, then the only color you can make is green. If you add red, you can now have green, red and yellow (green + red). If you add blue, you can now have green, red, blue, yellow (green + red), cyan (green + blue), magenta (red + blue) and white (green + red + blue). Keep going and you can see that the number of possible colors grows exponentially each time you add just one more color.

² α and β are constants that depend on the solver and hardware used

MemComputing's approach to the benchmark provided by PSA

The MemComputing team developed a custom software prototype using the underlying MemCPU Coprocessor to compute this benchmark. While MemComputing handles many data models and data formats (ILP, Max-SAT, SAT, QUBO, PUBO) the data set for this benchmark was in a non-standard form and most of the customization work was for handling this new format. MemComputing's approach is to provide plug and play technologies for its customers. Thus, they will build custom input/output wrappers as needed. In this case, the new format handler was turned around in less than 6 weeks.

Recall that the MemCPU Coprocessor is a software-based solution. It is hardware agnostic, meaning it can run on virtually any computer from a laptop to a supercomputer. The acceleration that MemComputing provides is commensurate to the starting performance of the hardware that it runs on. For this set of benchmarks, the MemCPU Coprocessor was run on a high-end Intel Xeon™ processor. Using this hardware, the



problem that would normally have taken over 70 hours was solved by MemComputing in approximately 1 hour, and instead of scaling exponentially, the scaling was linear. Those results are very impressive. Now, consider the second data set that was 3 times larger and would have taken over 13 billion years to solve even given today's fastest supercomputer. This problem was solved in 48 hours running the MemCPU Coprocessor on the high-end Xeon processor.

But wait, it gets even better. The MemComputing team was not happy with the performance. The team is made up of scientists with significant experience in high performance computing (HPC). One of the techniques used in HPC is to parallelize a problem and distribute the computations over

General-Purpose Graphical Processing Units (GP-GPUs). The team ran experiments and determined that in production, the MemCPU Coprocessor with distributed processing over GP-GPUs would bring the 70-hour problem down to sub-second time.

Conclusions

- MemComputing's technology can dramatically reduce the computing time needed for processing today's most complex logistics problems.
- MemCPU Coprocessors are a viable solution to at least some NP-Hard problems. (Additional experimentation is required to determine whether and where there may be limits.)

Bottom line: MemComputing can solve problems that are currently considered unsolvable because the time required could be years, decades or even eons!

Advancing Forward

- The purpose of the rapid proof of concept for PSA was to demonstrate the capabilities of the MemComputing team and their MemCPU technology.
- We met PSA's requirements and provided evidence and assurance of scaling needed for industrial sized problems.
- Additionally, the experience of working directly with the MemComputing team provided understanding that future collaborations can be as successful.



TRANSPORTATION LOGISTICS

MemComputing is working with companies on transportation logistics problems in airline, rail, trucking, busing and shipping. MemComputing helps solve traffic problems by optimizing the routing for taxis in our largest cities and by managing traffic signal assets for smart cities. With autonomous vehicles, MemComputing can analyze a larger set of inputs from the radar in order to significantly improve the resolution and accuracy. Offloading more and more of the autonomous vehicle computations, such as motion control and collision avoidance, to MemComputing reduces the amount of computer hardware required thus freeing up cargo space.

Logistics Beyond the Port

Logistics casts a net over far more than global ports. The importance of modernizing logistics with digital automation will impact all facets of management and control of the transportation, mobility and warehousing/storage of goods for satisfying consumer demands. It's fundamental to the supply chain. As B2B and B2C e-commerce continues to explode, and the volume of goods being transported worldwide is booming, business and consumer expectations for faster and faster order delivery will continue to place pressure on the entire transportation logistics and supply chain network. In turn this is putting strains on capacity, infrastructure and the workforce. It's making logistics problems seem impossible to solve in reasonable amounts of time. The digitalization of multi-modes of transportation such as marine, rail, trucking and air, as well as extended services such as postal services, couriers and messengers to track the real-time movement of goods into and out of business is an integral factor in the success of any industrial company. It's a must to secure and maintain a competitive advantage.

Note that the MemCPU Coprocessor is also just a tool. It is a bigger hammer for getting the job done. The MemComputing technology solutions will not replace Data Scientists. Companies will still require their scientists to develop the models for the problems that they wish to solve. In fact, they will be even more necessary because they will now be able to consider an infinite number of problems and models that would have been considered impossible up to this point. We believe that early adopter data scientists that take advantage of the MemComputing technology and integrate a MemCPU Coprocessor into their solutions will bring tremendous value to their organizations.

