AppFormix: Realize The Performance Of Your Cloud Infrastructure

AppFormix* Software Leverages New Intel® Resource Director Technology (Intel® RDT) Hardware Features to Improve Cloud Infrastructure Monitoring and Control

Industry Trends

The tools we’ve used for a generation to optimize infrastructure performance are insufficient when applied to the architectures of modern cloud infrastructure. Two foundational shifts are fundamentally redefining how IT operations professionals are preparing to meet the needs of a cloud-first world:

1. The shift to cloud-native applications: Applications are being rewritten and new ones developed – not for legacy environments where relatively static workloads are the norm, but for dynamic, scalable cloud environments. Motivating this shift is an implicit expectation that cloud and container infrastructure environments will deliver enhanced agility and improved ROI. This shift demands infrastructure transparency and real-time monitoring and analytics. Without these key pieces, neither applications nor their underlying plumbing can deliver the low-latency user experience end users have come to expect.

2. The shift to DevOps philosophy: Enterprises are moving away from IT silos and forming collaborative apps-driven cloud teams to speed time to market of enterprise software applications. This cultural transition has emphasized that application performance is a shared responsibility across both infrastructure operations and software development, and it demands a new set of tools that promote collaboration, offer real-time data analysis, and enable self-service infrastructure management.

Enterprises embracing this new environment of DevOps and realizing the competitive advantage gained from software innovation are requesting three key attributes:

1. Efficiency. Enterprises want to streamline cloud infrastructure management to deliver high-availability, high performance, and resource optimization.

2. Agility and Innovation. Enterprises want to provide application developers with tools that reduce friction and enable rapid success, replacing traditional IT silos with DevOps-style collaboration.

3. Improved ROI. Enterprises are looking for ways to operate large multi-cloud or hybrid cloud environments in the most cost-effective way, while delivering optimum performance.

Modern cloud management tools must deliver enterprises a “sweet spot” where monitoring, platform management, orchestration, security and compliance intersect. This new category of management capabilities for the DevOps era can be referred to as service optimization.

In collaboration with Intel, AppFormix* has integrated its cloud service optimization software with the Intel Resource Director Technology (RDT) hardware feature set. By using policy-based resource control, AppFormix* removes the guesswork of allocating resources and allows operators to manage their infrastructure efficiently. For the first time, the AppFormix* software in conjunction with the Cache Monitoring...
Technology (CMT), Memory Bandwidth Monitoring (MBM) and Cache Allocation Technology (CAT) features available in the new Intel® Xeon® E5 v4 processor family make it possible to enforce isolation between workloads and to detect and mitigate noisy-neighbor in real-time.

**AppFormix* Control for your cloud infrastructure**

Cloud infrastructure is shared infrastructure, and therefore resource contention is inevitable. Whether an environment is built on a cloud platform such as OpenStack* or a container runtime such as Docker*, the physical infrastructure is divided across multiple applications and often across multiple tenants. AppFormix* provides more isolation between workloads and visibility into performance, and a collaboration space that keeps everyone on the same team. The result is a cloud environment that is predictable, reliable and responsive to the needs of applications.

Through its unique ‘smart agent’ approach to telemetry and analysis, AppFormix* offers deep, meaningful insights in real-time by analyzing the system’s most accurate, high resolution and relevant data directly at the source -- all while consuming fewer resources than other monitoring systems.

**The AppFormix* software yields better-performing applications as well as happier application developers and operators.**

With AppFormix*, an operator can deliver to an application developer a self-service IT experience. App developers are able to consume infrastructure analytics within their applications and schedule workloads to achieve maximum performance. Operators manage access with user permissions, granting developers the ability to see their infrastructure, set alarms, monitor, and troubleshoot application performance issues on their own, which in turn significantly reduces the load on the help desk.

Dashboards and APIs provide visibility into each layer of the stack -- physical hardware, application software, and platform and management layers -- to show users how applications consume server, storage and networking resources in real-time.

Real-time analysis enables the best possible decision-making -- especially when it comes to orchestrating resources and detecting faults in the infrastructure. The dynamic nature of cloud native applications coupled with the shift to continuous deployment means that the demands placed by the applications on the infrastructure are constantly changing. AppFormix* automated, policy-driven resource orchestration and optimization removes the guesswork of allocating resources and allows operators to manage more servers with efficiency. Proactive remediation results in a Software Defined infrastructure that is more responsive to the needs of the applications, yielding better-performing applications as well as more productive application developers and operators.

Applications make demands on infrastructure, and the infrastructure makes promises to deliver. AppFormix* is the software that makes this interaction work in demanding production environments.

**Intel® Resource Director Technology (Intel® RDT)**

As introduced in the Intel® Xeon® processor E5-2600 v4 product family of server processors, Intel® RDT provides both monitoring and control (allocation) capabilities. The monitoring features enable characterization of the resource requirements of applications, for instance how much cache is needed to run at a certain level of performance, and can help detect “noisy neighbor” applications within the datacenter, which may slow down other higher priority workloads. In a complementary fashion, the allocation features help provide more control for prioritizing workloads, controlling noisy neighbors and improving performance determinism in complex and dynamic environments with many active processor cores. The constituent hardware technologies described below are leveraged extensively by the AppFormix* software suite to monitor and control the resource usage of containers and virtual machines.

**Visibility into Last-Level Cache (LLC) utilization per thread, app, container or VM:**

Cache Monitoring Technology (CMT) provides new insight by monitoring the last-level cache (LLC) utilization by individual threads, applications, or VMs. Example CMT usages include improved dynamic application characterization, “noisy neighbor” detection, performance debugging, advanced real-time provisioning and resource-aware scheduling decisions.

**Improved visibility into memory bandwidth utilization:**

Memory Bandwidth Monitoring (MBM) is an extension of CMT which provides per-thread memory bandwidth monitoring for all threads simultaneously for the first time -- enabling multiple VMs or apps to be independently tracked. New capabilities enabled include detecting “noisy neighbors” which over-utilize memory bandwidth, characterizing and debugging the performance of bandwidth-sensitive applications and more effective NUMA-aware scheduling, as visibility into both local and remote (e.g., QPI) bandwidth usage are provided.

**Control over last-level cache usage and prioritization:**

Cache Allocation Technology (CAT) improves control by prioritizing important data center VMs, containers or applications through software-guided redistribution of last-level cache (LLC) capacity. This ensures runtime determinism, protecting for instance important VMs, virtual switches or Intel Data Plane Development Kit (Intel DPDK) packet processing applications from resource contention, and preventing noisy neighbor interference across priority classes of workloads. Priority classes can also be created within the datacenter, prioritizing for instance interactive workloads over batch compute jobs.

**Improved isolation in code and data caching:**

Code and Data Prioritization (CDP) extends CAT to enable separate control over code and data placement in the last-level (L3) cache. Certain specialized types of workloads benefit with increased runtime determinism, enabling greater predictability in application performance.

**AppFormix* Software Architecture**

AppFormix* provides real-time control and monitoring of your cloud infrastructure
without high-touch modifications to sensitive ecosystem layers, and especially without slowing down production services.

The system is designed around a distributed analysis engine, called the AppFormix® Data Platform. This platform performs configurable, real-time evaluation of in-depth, high resolution metrics of the physical infrastructure and the virtualization layer executing VMs and containers. Distributed evaluation of metrics generates events on a message bus for prediction, optimization, and correlation analysis across the infrastructure. Users access the real-time metrics, events, and analysis results via a unified dashboard or by API.

**Overview**

The primary sub-systems are the Policy Controller, Data Platform, and Analytics. The Policy Controller manages policies for resource monitoring, analysis, and control. It also provides role-based access control. The Data Platform is a distributed system for metrics collection, analysis, and event generation. The Data Platform is fully cloud-aware and capable of associating raw resource usage data with elements of the infrastructure, virtualization, and application layers in a cloud environment. Analytics modules analyze metrics and events produced by Data Platform. Analytics modules can further analyze data across multiple elements and provide higher-level signals and information about the state of the software-defined infrastructure to operators and developers.

**User Interface**

AppFormix® exposes its functionality in two ways: REST-based APIs and a Web-based Dashboard. Dashboard is a graphical, Web-based client that runs in a browser. Dashboard enables the user to configure policies on the software-defined infrastructure and offers users a visual representation of resource metrics, alarms, health, and reports. It displays the relationship between entities (hosts, instances, projects, aggregates), and allows navigation of data across different axes. For example, the consumption of an instance may be viewed in the context of the host on which it executes and competes for resources with other instances.

**AppFormix® Policy Controller**

AppFormix® Policy Controller is a central policy engine that configures other AppFormix® components. User configuration is stored as policies that determine how monitoring, analysis, and control apply to selected elements (compute jobs, containers, VMs, etc.) in the software-defined data center. As elements enter and exit the system, the Policy Controller configures the AppFormix® components automatically according to current policies. For example, when a new virtual machine is created, the Policy Controller applies configuration for all policies for the Tenant that owns the virtual machine. The Policy Controller also provides role-based access control. Authentication is provided by integration with existing identity services, such as Keystone in OpenStack.

**AppFormix® Data Platform**

The AppFormix® Data Platform handles all resource data in the system, from raw metrics to configurable alarms. Using a distributed architecture, the Data Platform collects, processes, stores, and publishes resource metrics at multiple time scales.

**Solution Architecture.** AppFormix® Policy Controller, Analytics and Data Platform Software Stack. The AppFormix® solution is able to work with both Containers and VMs.

Or, the instance may be viewed on a chart with other instances in the same project, even when the instances all execute on different hosts.

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example, dynamically changing how much cache is allocated to each container running on the host.

**Real-Time Monitoring.** Examples of Real-Time Monitoring data as presented by the AppFormix® Dashboard

**AppFormix® Analytics**

AppFormix® Analytics is a modular subsystem that provides higher-order features to users. An analyzer module interfaces with the Data Platform and Policy Controller using REST-based APIs. An analyzer may listen for real-time data on the Data Platform’s Message Bus, access historic data in the Database, or both. In addition, an analyzer may publish data back into the Data Platform. An analyzer may also set policy in the Policy Controller, to configure resource monitoring or to orchestrate resources via a control policy. AppFormix® ships with several analyzers: Health, Reports, and Notifications.

The Health analyzer produces a risk rating to help users identify elements that are not meeting user-defined SLAs.

The Reports analyzer produces a report of resource consumption during a user-specified time period. These reports are useful for capacity planning or chargeback. The reports are stored in the Data Platform, and can be shared by users for collaboration.

The Notifications analyzer posts Alarms to third-party notification services, or an incident management system. This configurable module can send Alarm data to any external REST-based service.

**Cloud Platform Integrations**

The AppFormix® system integrates with platforms, such as OpenStack, Docker, and Kubernetes, via Adapter modules that discover physical and virtual elements in the environment and configures those elements in the Policy Controller. As an element enters and exits the system, the Adapter updates the Policy Controller.

**AppFormix® on the Intel® Xeon® processor E5-2600 v4 product family**

Software-defined infrastructure presents new challenges with respect to resource sharing. Prior to Intel® RD, resources such as L3 Cache and memory bus bandwidth could not be monitored or controlled. With AppFormix® and the Intel Resource Director Technology found in the Intel Xeon® E5 v4 processor, it is possible to monitor and identify anomalous resource utilization behavior and take mitigating action.

The AppFormix® Agent automatically detects if Intel® RDT features are available on a host. For a host equipped with Intel® Xeon® E5 v4 processors, the AppFormix® Agent is able to capture performance counters, such as L3 cache usage, cache misses, memory bandwidth, and instructions per cycle, provided by traditional performance monitoring counters, as well as the new CMT and MBM monitoring technologies. The AppFormix® Agent intelligently utilizes raw hardware counters and associates their values to elements of software-defined infrastructure, such as OpenStack virtual machines, Docker containers, Kubernetes pods, and native host workloads.

**Noisy Neighbor.** As shown where VM-2 uses most of the Last-level cache and in turn slows down VM-1 and other applications on the platform. AppFormix® combined with the components of Intel® RDT feature enables system and datacenter administrators to improve their visibility and control over how applications run together on server platforms, allowing enforcement of priority levels, advanced provisioning, and mitigating...
“noisy neighbors” in a fully dynamic environment.

As an example, consider a noisy neighbor that is consuming a disproportionate share of the L3 Cache. The AppFormix Agent can generate an alarm when it detects that an instance is consuming a large share of the L3 Cache. AppFormix Health analytics will receive the alarm on the Message Bus, and in response, may configure a policy that partitions the L3 Cache to reduce usage by the noisy instance and thereby maintain the SLA for high priority applications. Alternately, the AppFormix Policy Controller enables policies to be proactively defined to manage resource utilization for all instances, such that high priority tenants have guaranteed resource allocations required to meet performance SLAs. The host-local, policy-aware AppFormix Agent can react in real-time to ever-changing conditions to ensure policy compliance.

The Cache Allocation Technology (CAT) that is part of Intel® RDT offers cache allocation control in the form of a) absolute MB cache usage, b) percentage of cache usage, or c) overlapped or isolated cache regions. AppFormix exposes these controls in the policy for an instance, be it a VM or container. Thus, a policy may be created to provide consistent SLAs and performance guarantees to applications.

The AppFormix Health module uses a simple REST interface of the Policy Controller to dynamically update the Cache Allocation of an instance.

The following sample curl command depicts the API call:

curl -i \  
-H 'Content-Type: application/json' \  
-X PUT \  
-d '{ "CacheAllocation": 5 }' \  
http://<PolicyController>:7000/appformix/v1.0/instance/<instance-id>

Experimental Results

The performance benefits of the Intel CAT feature can be demonstrated using two back-to-back connected servers.

The load generator runs on Server-1, which is a previous-generation platform including a two socket configuration based on Intel® Xeon® L5520 processors at 2.27GHz. Each socket has 8 logical threads (SMT enabled) and 8192 KB of L3 Cache. The load generator requests the same file using 22 processes and 24 concurrent connections.

Server-2 is the system under test, which consists of an NGINX Web server with a total of 88 threads evenly distributed on the two socket Intel® Xeon® CPU E5-2699 v4 @ 2.20GHz. Each socket has 44 logical threads (SMT on) and 56320 KB of L3 Cache. The NGINX processes serve files of different sizes: 10MB, 1MB, 100KB, 10KB

The Noisy entity used for the purposes of the experiment is a standard benchmark called Stream® and runs 11 processes per socket evenly distributed on each socket on Server-2. The CAT masks are applied on both sockets via a cgroups kernel patch in an automated fashion using the AppFormix framework. The effective CAT mask applied to contain the “noisy neighbor” threads is 0x0003, mapping to approximately 10% of the cache, while the web server threads use the full cache.

Performance results are shown below for two key metrics – throughput and effective web server response time as observed at the load generator. Both metrics are improved. Absolute performance is improved by up to 27% by containing the “noisy neighbor” as shown below.

Latency metrics also improve – for instance the average response time of the server to a given request reduces up to 51% in the presence of a noisy neighbor as shown in the figure below. In addition, we also observed an up to 122% reduction in worst-case web server response times.

Summary

The combination of AppFormix software suite and Intel’s Cache Allocation Technology (CAT) up to a 51% reduction in average response time (latency) can be achieved, improving the experience for end users.
**AppFormix** and **Intel** Resource Director Technology Solution Highlights

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<th>SOLUTION FEATURE</th>
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| AppFormix Analytics | • AppFormix software in conjunction with the Intel RDT available in the new Intel® Xeon® E5 v4 processor make it possible to detect noisy-neighbors in real-time.  
• Enables collaboration between Developers and Operators |
| AppFormix Control | • AppFormix software in conjunction with Intel’s Cache Allocation Technology (CAT) instruction set makes it possible to enforce isolation between workloads and to detect and mitigate noisy-neighbors in real-time.  
• Improved Application Performance  
• Potentially Improved Infrastructure ROI |


For more information on the Intel® Resource Director Technology (RDT), visit [www.intel.com/go/url](http://www.intel.com/go/url)


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1. Detailed AppFormix configuration:

   **Baseline configuration:** NGINX web server (88 threads across both sockets) serving requests of 10MB, 1MB, 100KB, 10KB to external load generation system (below) on Ubuntu14.04, Kernel v4.4 + Intel CAT v16 patch + MBM latest patch, 2 Intel® Xeon® processor E5-2699 v4, 2.2GHz, 22 cores, 64GB DDR4-2133, standard RDIMMs, generic mass-market 7200RPM HDD, 10Gb network links via dual-port Intel X540-AT2 NICs (Model X540T2G1P5), BIOS Grantley 0271 with production microcode 0xE, C1E disabled and turbo disabled for test repeatability. Source is AppFormix* as of March 3rd, 2016.

   **New configuration:** Intel’s Cache Allocation Technology (CAT) enabled via the AppFormix® software suite, Linux cgroups patches (CAT v16 patch mentioned above: [https://github.com/fyu1/linux/tree/cat16.1](https://github.com/fyu1/linux/tree/cat16.1)) and set to restrict the “noisy neighbor” applications to 10% of the L3 cache (effective CAT mask 0x00003 on a 20-way LLC).

2. "Noisy neighbor" applications: 11 processes per socket of the industry-standard “Stream” benchmark, publically available at [https://www.cs.virginia.edu/stream/ref.html](https://www.cs.virginia.edu/stream/ref.html). One parameter changed to increase array size: stream.c #define STREAM_ARRAY_SIZE 100000000

**External Load generation system:** wg/WRK benchmarking tool running 22 threads on Ubuntu Linux 14.04, based on 2 Intel Xeon L5520@ 2.27GHz CPUs, 24GB DDR3-1067 with 10Gb networking (Intel X540-AT2 NICs) over CAT7 copper

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors.
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