Ginseng: Market-Driven LLC Allocation

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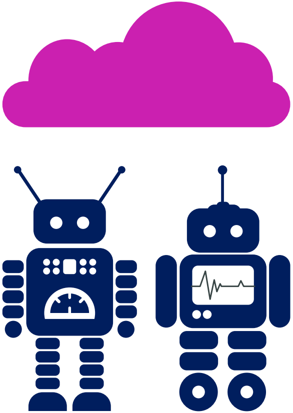
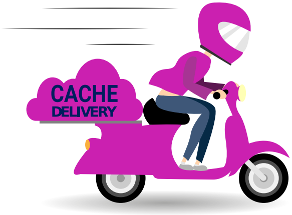
Infrastructure-as-a-Service (IaaS) Model



- IaaS cloud providers rent a bundle of resources in the form of a guest virtual machine (VM) to their clients

- Cloud clients need to rent VMs with the resources to sustain their highest workload
- They will prefer to rent resources only when it is really necessary
  - This will reduce idle resources
  - Hence, the provider can consolidate more clients per physical machine

The Resource-as-a-Service (RaaS) Model



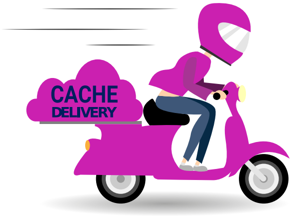
The future of the Infrastructure-as-a-Service (IaaS) cloud is the **RaaS** cloud, characterized by:

- Fine resource granularity
- Fine time granularity
- Market-driven resource pricing

More details in:

- *The Rise of RaaS: the Resource-as-a-Service Cloud*. Orna Agmon Ben-Yehuda, Muli Ben-Yehuda, Assaf Schuster, Dan Tsafrir. CACM, July 2014.
- *The Resource-as-a-Service (RaaS) Cloud*. Orna Agmon Ben-Yehuda, Muli Ben-Yehuda, Assaf Schuster, Dan Tsafrir. HotCloud, June 2012.

Dynamic Last-Level Cache Allocation (LLC)



- We want to dynamically allocate LLC using the RaaS model
  - Fine allocation granularity
  - Fine time granularity
  - Market-driven pricing

- We can utilize Intel's new LLC allocation technology for that end

Reminder: How Cache Works

- Upon a memory access, the cache follows this algorithm:
  - Calculate the **set**: hash value of the memory address
  - Scan the **ways** over that **set** for this memory address
  - If not found:
    - Read it from the memory
    - Store it in the least-recently used (LRU) **way** over that **set**

	Way 1	**Way 2**	⋯	**Way m**
Set 1	line	line	⋯	line
Set 2	line	line	⋯	line
⋮	⋮	⋮	⋱	⋮
Set n	line	line	⋯	line

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CAT allows the host to restrict the store only to a subset of ways, depending on the guest that issued the memory access

How should we allocate the LLC in a public cloud?

- What is the benefit of each guest from the cache?
- How can the cloud provider know which guest will benefit from LLC the most?

Some applications can benefit from more cache (cache-utilizers)

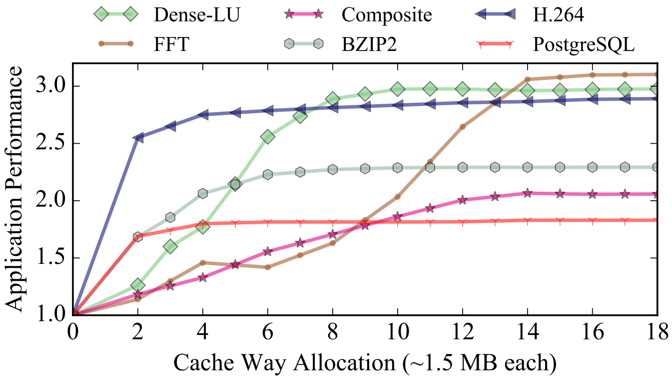
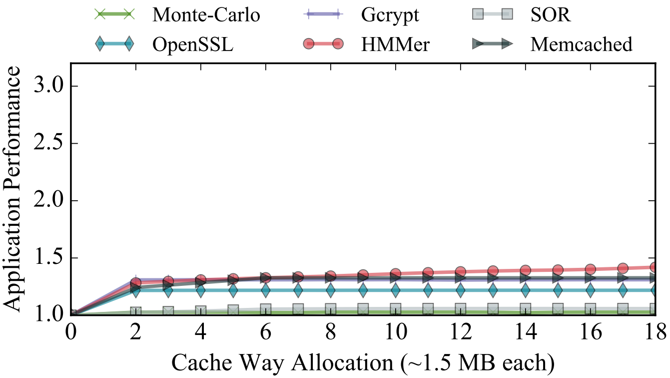


Figure: Benchmarks from Phoronix Test Suite: `http://www.phoronix-test-suite.com/`

Cache-Neutral Applications

But not all applications can exploit the cache to increase performance (cache-neutral)



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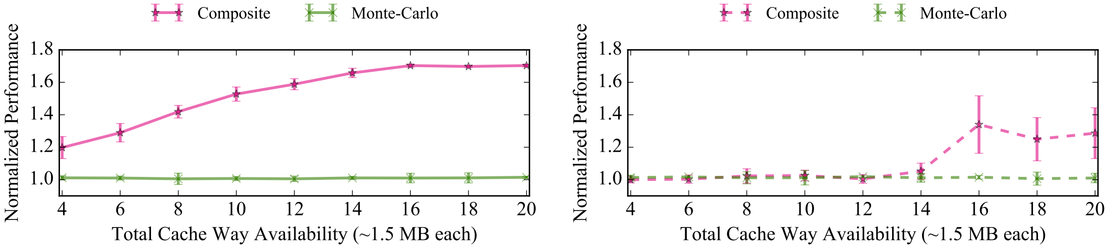
Cache-Polluter Applications

- Some cache-neutral applications will pollute the cache (cache-polluters)
  - E.g. an application that reads or writes a stream of data will pollute the cache with this data but will not use it again in the near future



(a) ***Partitioned Cache*** **(b)** ***Shared Cache***

Figure: Composite-Scimark (cache-utilizer) and Monte-Carlo (cache-neutral)

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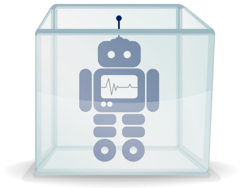
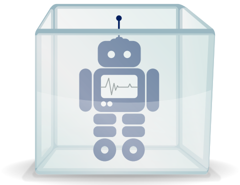
White Box vs. Black Box



White box approaches cannot work in a real commercial cloud

- What is the guest doing? What should be measured? How?
- How much is the performance worth to the client?
- Whose fault is it that the guest's performance is low? Maybe the software is inefficient?

White Box vs. Black Box



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Black box approaches cannot work in a real commercial cloud

- Guest measurements: results can be mis-reported
- Host measurements: High miss ratio can be faked to induce the host to allocate more cache

Designing a New Resource Allocation Mechanism

The *Ginseng* system uses an **economic mechanism** (VCG) that incentivizes even **black-box** guests to reveal how much cache is **worth to them**

- **VCG:** auction mechanism designed by Vickrey (1961), Clarke (1971), Groves (1973)

Using this knowledge, *Ginseng* can find the allocation that maximizes the **social welfare**: sum of guest valuations

Ginseng Protocol (VCG)

The host announces an auction every 10 seconds

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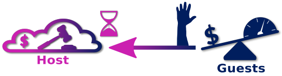
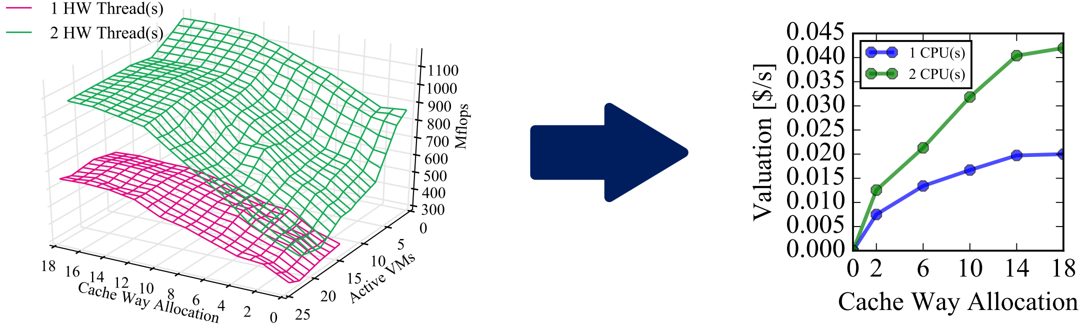


Each guest bids with a valuation for each quantity of cache ways — how much it is worth, subjectively

Bidding and Valuation

Clients should be able to evaluate, in economic terms, their benefit from the cache



(a) ***Performance profiling*** **(b)** ***Valuation***

Figure: Composite-Scimark profiling and valuation function

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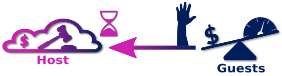

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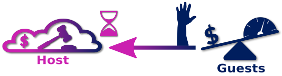

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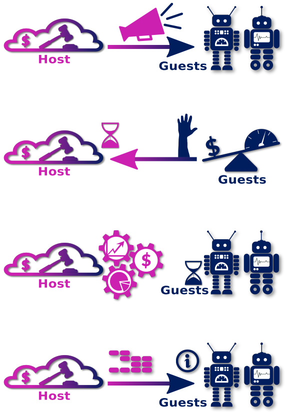
The host informs the guests of their allocation and charges them according to the **exclusion-compensation** principle

The Exclusion-Compensation Principle



The **exclusion-compensation** principle:

- Each guest pays for the damage it inflicted on the other guests in the system

As a result:

- The guests cannot improve their status by bidding a higher or a lower value
- Prices are **not** uniform
- They may drop to a minimal price (possibly zero) if there is no demand for the LLC

How should we allocate the LLC in a public cloud?

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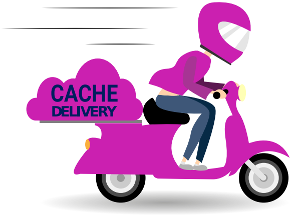
Allocating LLC with the Resource-as-a-Service Model



Requirements for LLC allocation with the RaaS model:

- Fine allocation granularity
- Fine time granularity
- Market-driven pricing

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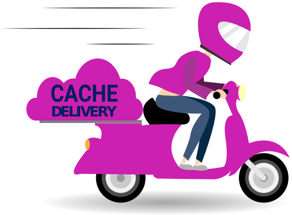

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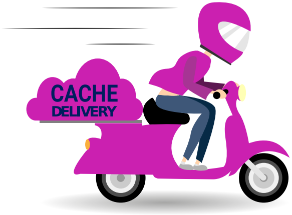

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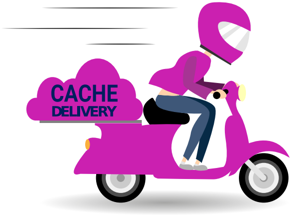

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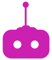

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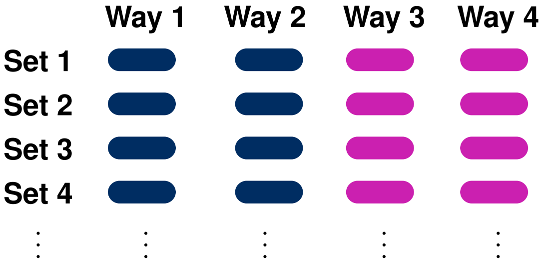

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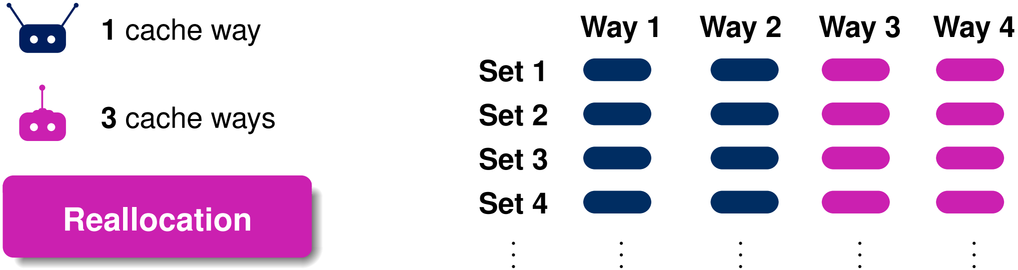

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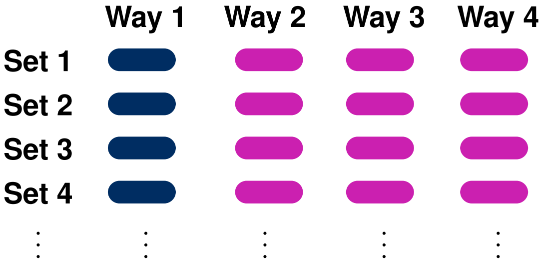
1 cache way

3 cache ways

Expected Outcome



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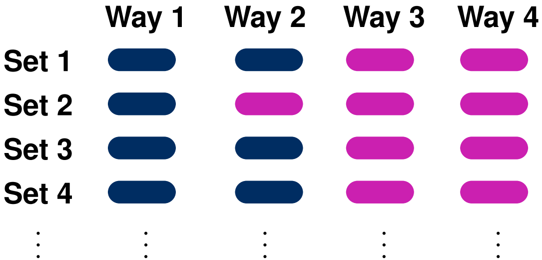
Actual Outcome



Measuring the Leakage Effect

- We designed an application that takes advantage of the cache leakage by
  - Ensuring its data fits perfectly in its cache ways
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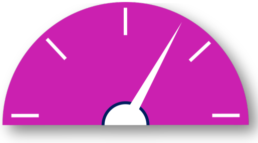

- Performance varied by **up to 4%** from the baseline values
  - Up to 1.1% on average for all of the workloads
- **Unnoticeable** cache leakage in real world scenarios

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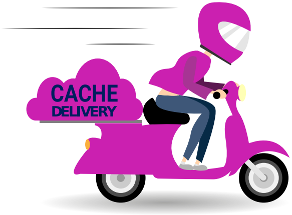

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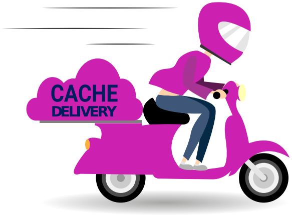

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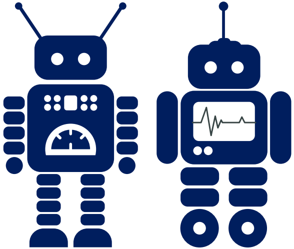
Evaluating our Solution

Experimental Methodology



- Each guest VM ran one application and served 10 customers, one at the time
- It valued each customer differently, for example:
  - High paying customers will have a high valuation
  - Medium paying customers will have a medium valuation
  - Non-paying customers will have a low valuation

Evaluation on a Growing Number of VMs

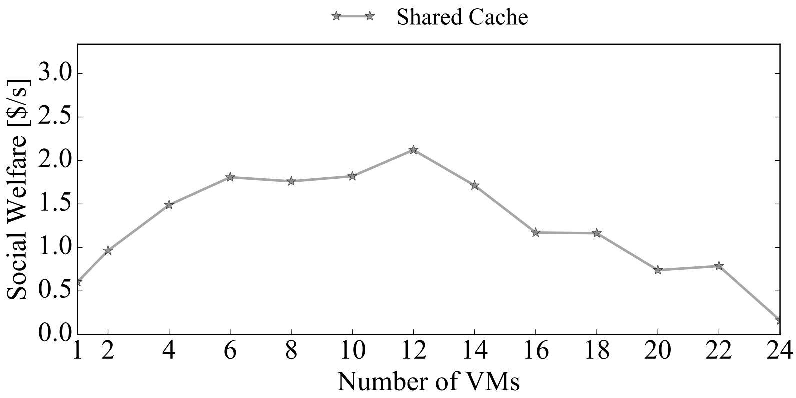


Figure: All guests run *Fast Fourier Transform* with 1 high-valuation customer, 1 medium-valuation customers and 8 low-valuation customers.

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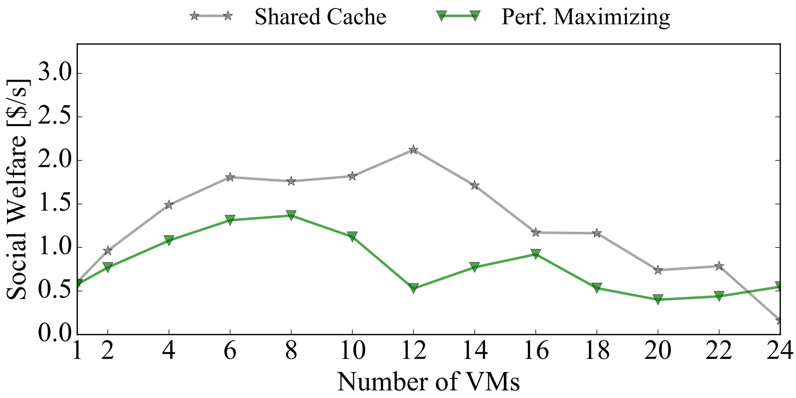

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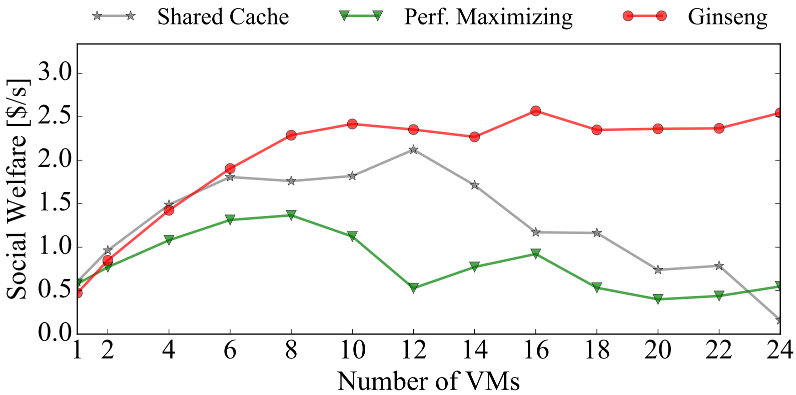

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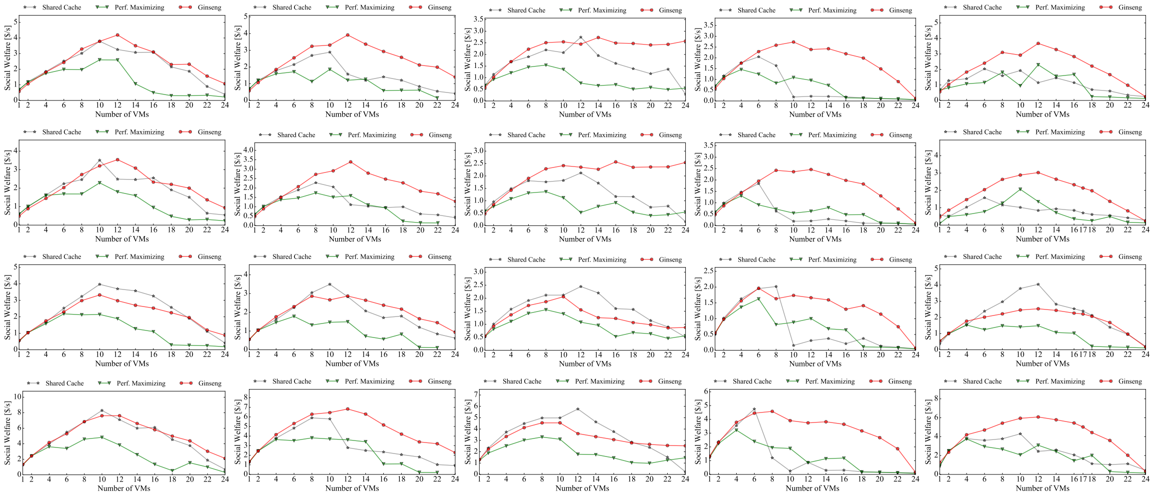
Thousands of Experiments



Compared to Performance Maximizing

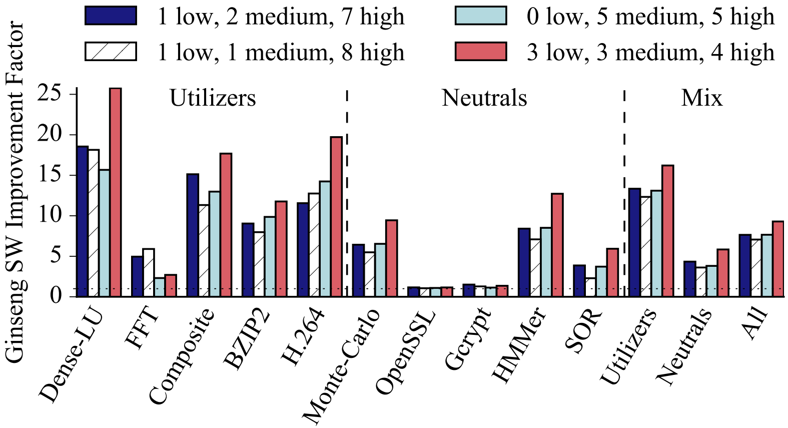
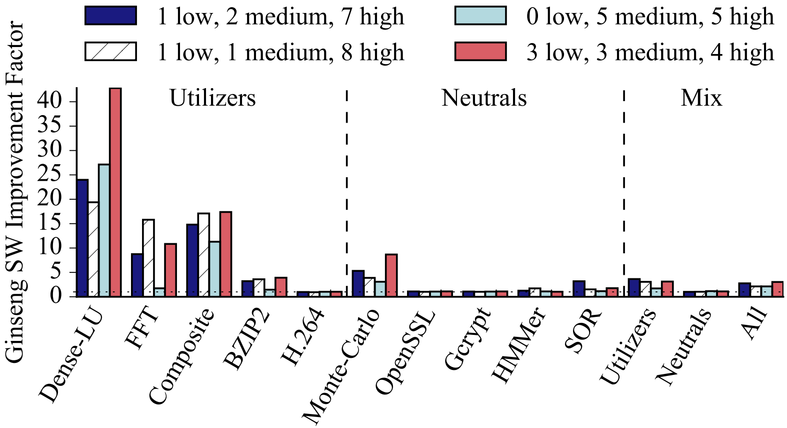


Figure: Maximum improvement factor of *Ginseng* compared to the performance-maximizing method.

Compared to Shared Cache



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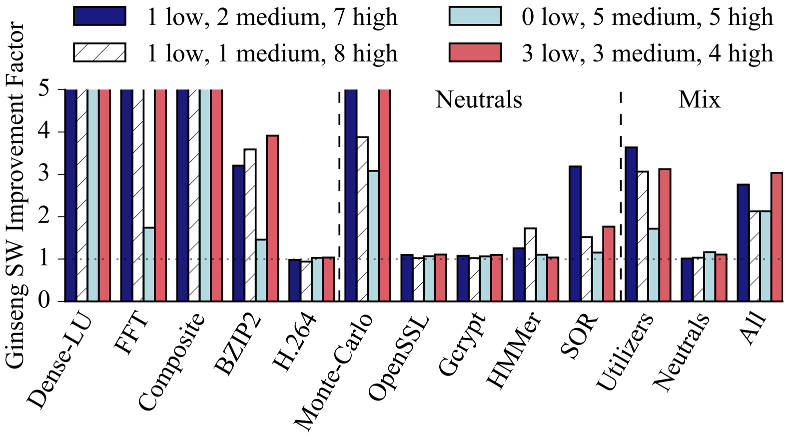
Compared to Shared Cache (ZOOM)



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Conclusions

- *Ginseng* efficiently allocates LLC to selfish black-box guests while maximizing their aggregate benefit
- The guests utilize their cache fast enough to allow such rapid changes in the allocation without any substantial effect on their performance

Questions?

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