

Memory Flipping: A threat to NUMA virtual machines in the Cloud

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Outline for Section 1

1. Context

- 1.1 System Virtualization
- 1.2 Structuring Elements
- 1.3 Numerals and Mathematics
- 1.4 Figures and Code Listings
- 1.5 Citations and Bibliography

2. Light Frames

- 2.1 Blind Text
- 2.2 Structuring Elements
- 2.3 Numerals and Mathematics
- 2.4 Figures and Code Listings
- 2.5 Citations and Bibliography

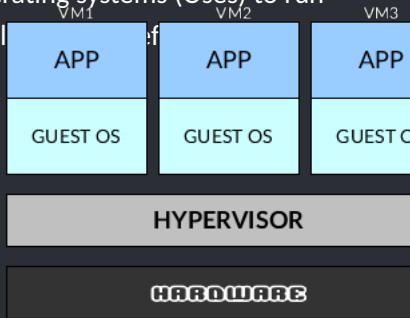
Context

System Virtualization

System virtualization enables several operating systems (Oses) to run on a physical server. These Oses run in blocks of virtual machines (VMs).

The hypervisor is in charge of :

- VM administration
- Block devices
- Network devices
- Scheduling
- Memory management

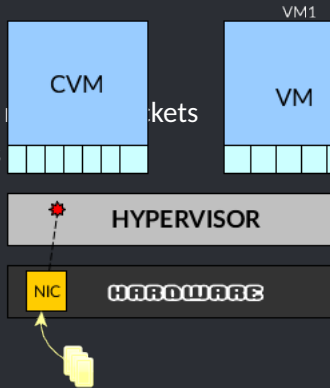


Context

System Virtualization - Network

The hypervisor handles incoming and outgoing packets to/from VMs. In general, when a packet arrives

- a hardware interrupt is raised and
- caught by the hypervisor.

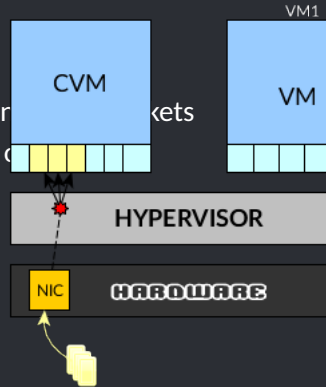


Context

System Virtualization - Network

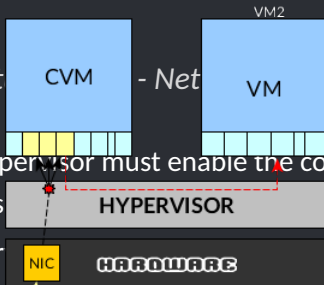
The hypervisor handles incoming and outgoing network packets to/from VMs. In general, when a packet arrives on the NIC, a hardware interrupt is raised and

- a hardware interrupt is raised and
- caught by the hypervisor.
- The packet is then reconstructed in the hypervisor memory (or CVM¹ memory)



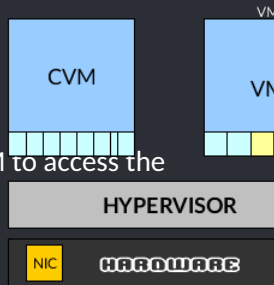
Context

System Virt



Now, the hypervisor must enable the concerned VM to access the packet in his

- Memor



Context

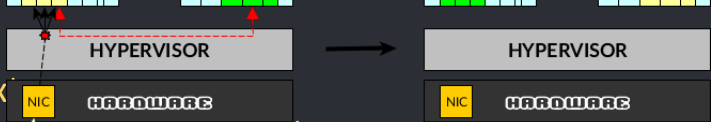
System Virtualization - Network

Now, the hypervisor must enable the concerned VM to access the packet in his memory space.

- Memory-copy(**Too costly**)
- **Memory flipping**

Definition

Memory flipping is the process where the hypervisor gives access grants on the pages (storing the packet data) to the concerned VM. To counterbalance, the VM offers some pages for the CVM.



Context

System Virtualization - Network - Memory Flipping

- Better throughput than memory copy
- Works well on uniform memory architectures



Context

System Virtualization - Network - Memory Flipping

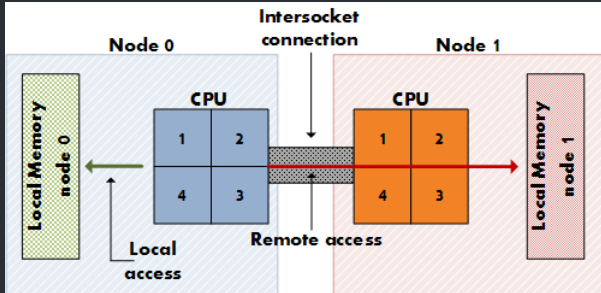
- Better throughput than memory copy
- Works well on uniform memory architectures

How about NUMA architectures ?

Context

System Virtualization - NUMA (Recall)

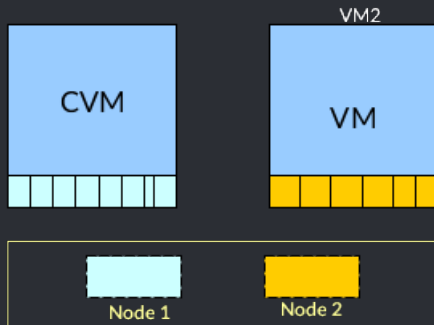
- A remote memory **cost more** than a local access.
- Modern Oses updated their memory allocation and scheduling policies to take into account NUMA.



Problematic

System Virtualization - Network - NUMA

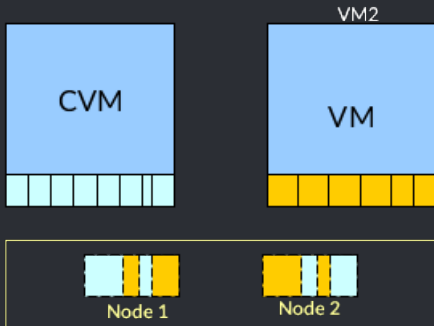
In a virtualized NUMA environment, the trend is to allocate a whole node for the CVM. Hence, *the CVM's memory is usually on a different NUMA node than those of VMs.*



Problematic

System Virtualization - Flipping - NUMA

With this layout, repeated memory flipping operations leads to the VM's **transparent memory migration** from one node to another.

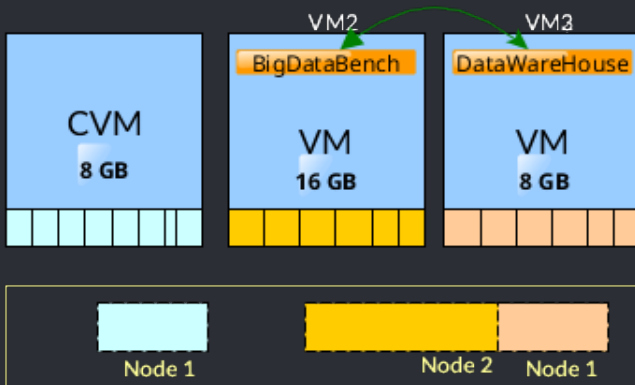


Problematic

System Virtualization - Flipping - NUMA

To confirm this hypothesis, we ran an E-Commerce benchmark from the **BigDataBench suite (Eight TPC-DS Web Queries)**.

We monitor VM2's mem % on each node during the experiment



Problematic

System Virtualization - Flipping - NUMA

Lists and locales

Lorem ipsum dolor sit amet

- Nulla nec lacinia odio.
Curabitur urna tellus.
 - Fusce id sodales dolor. Sed
id metus dui.
 - » Cupio virtus licet mi vel
feugiat.
- 1. Donec porta, risus porttitor
egestas scelerisque video.
 - 1.1 Nunc non ante fringilla,
manus potentis cario.
 - 1.1.1 Pellentesque servus
morbi tristique.

Nechť již hříšné saxofony d'áblů rozzvučí síň úděsnými tóny waltzu, tanga a quickstepu! Nezvyčajné krdle šťastných figliarskych d'atľov učia pri kótovanom ústí Váhu mĺkveho koňa Waldemara obžierať väčšie kusy exkluzívnej kôry. The quick, brown fox jumps over a lazy dog. DJs flock by when MTV ax quiz prog. "Now fax quiz Jack!"

Text blocks

*In plain, example, and **alert** flavour*

This text is highlighted.

A plain block

This is a plain block containing some **highlighted text**.

An example block

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An alert block

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Definitions, theorems, and proofs

All integers divide zero

Definition

$$\forall a, b \in \mathbb{Z} : a \mid b \iff \exists c \in \mathbb{Z} : a \cdot c = b$$

Theorem

$$\forall a \in \mathbb{Z} : a \mid 0$$

Proof

$$\forall a \in \mathbb{Z} : a \cdot 0 = 0$$



Numerals and Mathematics

Formulae, equations, and expressions

$$1234567890 \quad 1234567890 \quad \hat{x}, \check{x}, \tilde{a}, \bar{a}, \dot{y}, \ddot{y} \iiint f(x, y, z) \, dx dy dz$$

$$\frac{1}{1 + \frac{1}{2 + \frac{1}{3 + x}}} + \frac{1}{1 + \frac{1}{2 + \frac{1}{3 + x}}}$$

$$F : \begin{vmatrix} F''_{xx} & F''_{xy} & F'_x \\ F''_{yx} & F''_{yy} & F'_y \\ F'_x & F'_y & 0 \end{vmatrix} = 0$$

$$\iint_{\mathbf{x} \in \mathbb{R}^2} \langle \mathbf{x}, \mathbf{y} \rangle \, d\mathbf{x}$$

$$\overline{\overline{a\alpha^2 + \underline{b\beta} + \overline{\overline{d\delta}}}}$$

$$]0,1[+ \lceil x \rceil - \langle x, y \rangle$$

$$e^x \approx 1 + x + x^2/2! + x^3/3! + x^4/4!$$

$$\binom{n+1}{k} = \binom{n}{k} + \binom{n}{k-1}$$

Figures

Tables, graphs, and images

Faculty	With T _E X	Total	%
Faculty of Informatics	1 716	2 904	59.09
Faculty of Science	786	5 275	14.90
Faculty of Economics and Administration	64	4 591	1.39
Faculty of Arts	69	10 000	0.69
Faculty of Medicine	8	2 014	0.40
Faculty of Law	15	4 824	0.31
Faculty of Education	19	8 219	0.23
Faculty of Social Studies	12	5 599	0.21
Faculty of Sports Studies	3	2 062	0.15

Table: The distribution of theses written using T_EX during 2010–15 at MU

Figures

Tables, graphs, and images

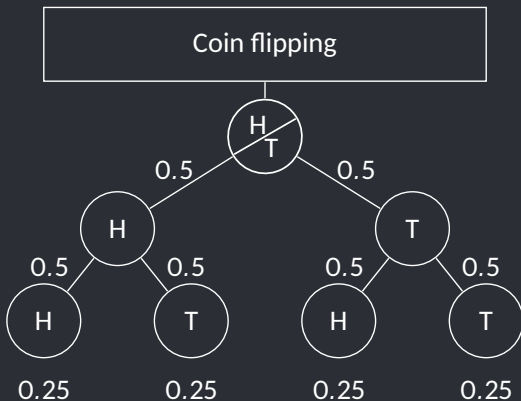


Figure: Tree of probabilities – Flipping a coin²

²A derivative of a diagram from texample.net by cis, CC BY 2.5 licensed

Code listings

An example source code in C

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

// This is a comment
int main(int argc, char **argv)
{
    while (--c > 1 && !fork());
    sleep(c = atoi(v[c]));
    printf("%d\n", c);
    wait(0);
    return 0;
}
```

Citations

T_EX, L^AT_EX, and Beamer

T_EX is a programming language for the typesetting of documents. It was created by Donald Erwin Knuth in the late 1970s and it is documented in *The T_EXbook* [1].

In the early 1980s, Leslie Lamport created the initial version of L^AT_EX, a high-level language on top of T_EX, which is documented in *L^AT_EX: A Document Preparation System* [2]. There exists a healthy ecosystem of packages that extend the base functionality of L^AT_EX; *The L^AT_EX Companion* [3] acts as a guide through the ecosystem.

In 2003, Till Tantau created the initial version of Beamer, a L^AT_EX package for the creation of presentations. Beamer is documented in the *User's Guide to the Beamer Class* [4].

Bibliography

$T_{\text{E}}\text{X}$, \LaTeX , and Beamer

- [1] Donald E. Knuth. *The $T_{\text{E}}\text{X}$ book*. Addison-Wesley, 1984.
- [2] Leslie Lamport. *\LaTeX : A Document Preparation System*. Addison-Wesley, 1986.
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- [5] A. Mertz and W. Slough. Edited by B. Beeton and K. Berry. *Beamer by example* In TUGboat, Vol. 26, No. 1., pp. 68-73.

Outline for Section 2

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Jabberwocky

Lewis Carroll



'Twas brillig, and the slithy toves
Did gyre and gimble in the wabe;
All mimsy were the borogoves,
And the mome raths outgrabe.

“Beware the Jabberwock, my son!
The jaws that bite, the claws that catch!
Beware the Jubjub bird, and shun
The frumious Bandersnatch!”

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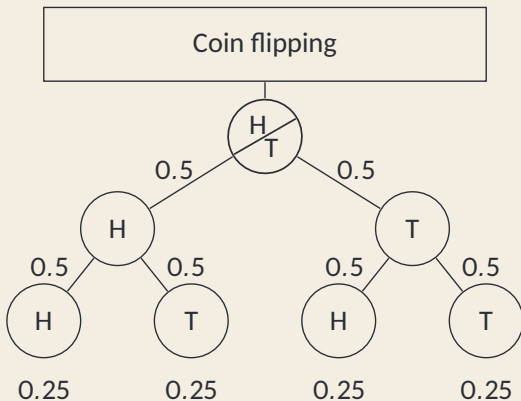


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