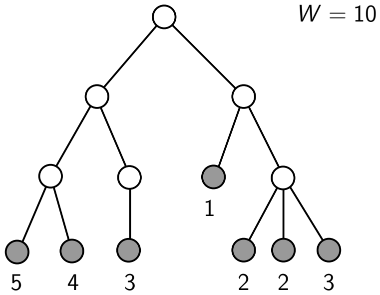
# Comment trouver un sujet de recherche?

Anne Benoit
LIP, Ecole Normale Supérieure de Lyon, France

Semaine sport-études des L3 – 28 mai 2021

# Un premier problème: Placement de répliques dans des arbres

- On nous donne un arbre; les feuilles de l'arbre sont des clients
- Un certain nombre de requêtes par unité de temps par client
- But: placer des serveurs pour satisfaire toutes les requêtes
- Le problème est-il bien posé ?



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**Il faut clarifier certains points**

- Combien de requêtes sont traitées par un serveur ?
- On commence par un cas simple, $W$ requêtes max par serveur
- Quelle est la fonction objective ?
- Minimiser le nombre de serveurs à placer
- Mais encore ?
- Quelle est la politique de service des clients par les serveurs ?

# Un premier problème: Placement de répliques dans des arbres

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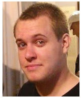
Politiques au plus près, plus haut dans l'arbre, plusieurs serveurs par clients, on peut rajouter de l'énergie, de la résilience, ça fait plein de problèmes rigolos !

Premier exemple (rapide) illustrant la recherche de sujet de recherche: broder sur les règles du jeu, établir la complexité des problèmes... ☺

# Un sujet plus détaillé: Replication Is More Efficient Than You Think

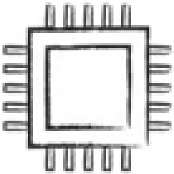
   

Anne Benoit[1], Thomas Herault[2], Valentin Le Fèvre[1], Yves Robert[1,2]

1. LIP, Ecole Normale Supérieure de Lyon, France
2. ICL, University of Tennessee Knoxville, USA

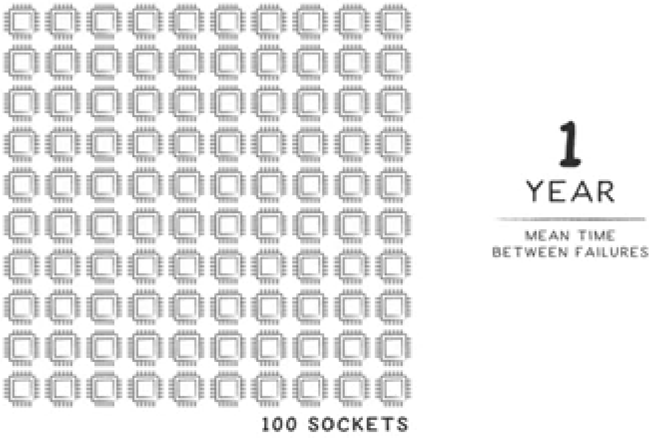
Semaine sport-études des L3 – 23 janvier 2020

# Scale Is The Enemy



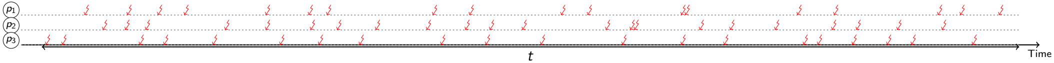

*Chouette, mon ordi est fiable !*

# Scale Is The Enemy

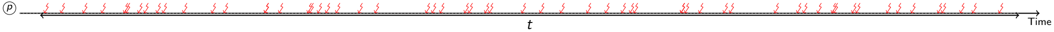



*Pas tant que ça ?*

# Scale Is The Enemy



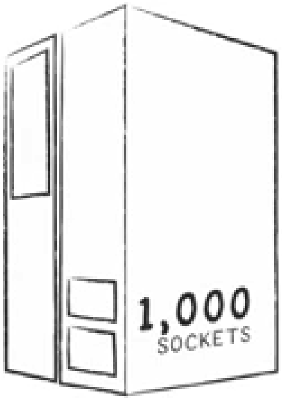

If three processors have around 20 faults during a time $t$ $(\mu = \frac{t}{20})$...




...during the same time, the platform has around 60 faults $(\mu_N = \frac{t}{60})$

$$\mu_N = \frac{\mu}{N}$$

# Scale Is The Enemy

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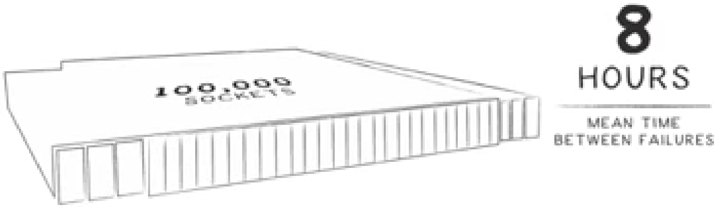


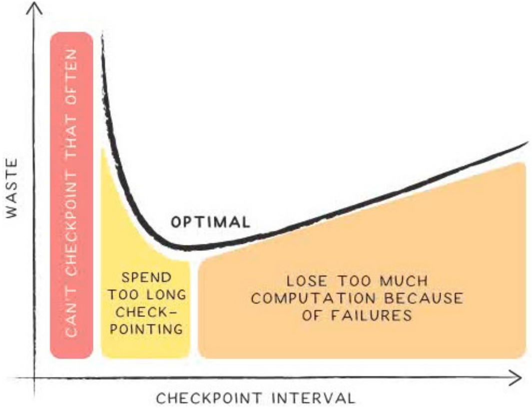
# Scale Is The Enemy

**Need to checkpoint!**

... i.e., periodically save the application so you don't have to restart from scratch when a failure occurs

But when should we checkpoint?
Scheduling matters ☺

# Optimal Checkpointing Interval




*Par exemple, Bob qui rédige sa thèse...*

# The Young/Daly Formula

Period $T$, minimize overhead $\mathbb{H}(T) = \frac{\mathbb{E}(T+C)}{T} - 1$

**Theorem**

$$T_{opt} = \sqrt{\frac{2C}{\lambda_N}} = \sqrt{2C\mu_N} = \Theta(\lambda^{-\frac{1}{2}}) \quad (1)$$

$$\mathbb{H}_{opt} = \sqrt{2C\lambda_N} + o(\lambda^{\frac{1}{2}}) = \Theta(\lambda^{\frac{1}{2}}) \quad (2)$$

Recall that $\lambda_N = N\lambda = \frac{1}{\mu_N} = \frac{N}{\mu}$

*... mais où est le problème alors ? Sur quoi peut-on chercher ?*

# Outline

1 Replication

2 New Strategy

3 Digression

4 Experiments

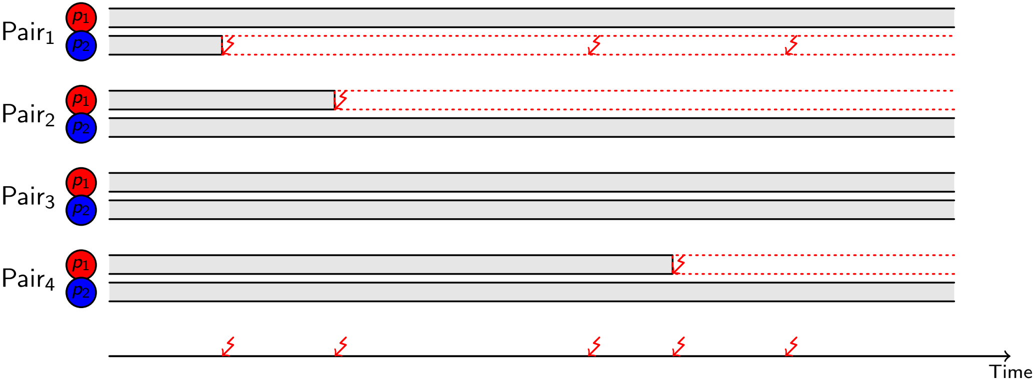
# Replication

- Full replication: efficiency $< 50\%$
- Can replication+checkpointing be more efficient than checkpointing alone?
- Study by Ferreira et al. [SC'2011]: yes
- Revisited by Hussain, Znati and Melhem [SC'2018]: yes

# Model by Ferreira et al. [SC'2011]

- Platform with $N = 2b$ processors arranged into $b$ pairs
- Parallel application with $b$ processes, each replicated
- When a replica is hit by a failure, it is not restarted
- Application fails when both replicas in one pair have been hit

# Example



# Why Replication?

With $\mu = 5$ years, time to reach 90% chance of fatal failure:

| | |
|---|---|
| No replication | 24 minutes for $N = 100,000$ |
| No replication | 12 minutes for $N = 200,000$ |
| Replication | 85 hours for $N = 200,000$ ($b = 100,000$ pairs) |

# Checkpointing Period

- Replication combined with periodic checkpoint-restart à la Young/Daly
- Restart after interruption instead of after first failure
- Many failures needed to interrupt the application
  $\Rightarrow$ checkpointing period much larger than without replication
- Optimal period?

# Mean Time To Interruption

- $N = 2b$, $b$ processor pairs
- $n_{\text{fail}}(2b)$ expected number of failures to interrupt the applications
- MTTI $M_N = M_{2b} =$ Mean Time to Interruption
  $\Rightarrow$ replaces MTBF from the application perspective

$$M_N = M_{2b} = n_{\text{fail}}(2b) \times \mu_{2b} = n_{\text{fail}}(2b) \times \frac{\mu}{2b} = \frac{n_{\text{fail}}(2b)}{2\lambda b} \quad (3)$$

# Mean Time To Interruption

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**Theorem**

$$n_{fail}(2b) = 1 + 4^b \Big/ \binom{2b}{b} \approx \sqrt{\pi b}$$

# A Little Bragging

$$M_{2b} = \int_0^{\infty} (1-(1-e^{-\lambda t})^2)^b dt$$

$$x = \frac{e^{-\lambda t}}{2} \Rightarrow n_{\text{fail}}(2b) = 2b4^b \int_0^{\frac{1}{2}} x^{b-1}(1-x)^b dx = 2b4^b B(\frac{1}{2}, b, b+1)$$

$$B(z,u,v) = \int_0^z x^{u-1}(1-x)^{v-1} dx = \frac{z^u}{u} \times {}_2F_1\left[\begin{matrix} u, & 1-v \\ & u+1 \end{matrix}; z\right]$$

$${}_2F_1\left[\begin{matrix} u, & v \\ & w \end{matrix}; z\right] = \sum_{n=0}^{\infty} \frac{\langle u\rangle_n \langle v\rangle_n}{\langle w\rangle_n} \frac{z^n}{n!} = 1 + \frac{uv}{1!w}z + \frac{u(u+1)v(v+1)}{2!w}z^2 + \dots$$

$$B(\frac{1}{2}, b, b+1) = \frac{1}{b2^b} \times {}_2F_1\left[\begin{matrix} b, & -b \\ & b+1 \end{matrix}; \frac{1}{2}\right]$$

$${}_2F_1\left[\begin{matrix} b, & -b \\ & b+1 \end{matrix}; \frac{1}{2}\right] = \frac{\sqrt{\pi}\,\Gamma(b+1)}{2^{b+1}} \left[\frac{1}{\Gamma(b+1)\Gamma(\frac{1}{2})} + \frac{1}{\Gamma(b+\frac{1}{2}))\Gamma(1)}\right]$$

$$\Gamma(z) = \int_0^{\infty} x^{z-1}e^{-x}dx, \Gamma(1) = 1, \Gamma(b+1) = b!, \Gamma(\frac{1}{2}) = \sqrt{\pi}, \Gamma(b+\frac{1}{2}) = \frac{\sqrt{\pi}(2b)!}{4^b b!}$$

A L

## Maple helped find the formula

$$M_{2b} = \int_0^\infty (1-(1-e^{-\lambda t})^2)^b dt$$

$$M_{2b} = \int_0^\infty e^{-\lambda bt}(2-e^{lat})^b)dt$$

$$M_{2b} = \sum_{i=1}^{b} 2^i \binom{b}{i} (-1)^{b-i} \int_0^\infty e^{-\lambda(2b-i)t} dt$$

$$M_{2b} = \sum_{i=1}^{b} 2^i \binom{b}{i} (-1)^{b-i} \frac{1}{\lambda(2b-i)}$$

$$n_{\text{fail}}(2b) = 2\lambda b M_{2b} = \sum_{i=1}^{b} 2^i \binom{b}{i} (-1)^{b-i} \frac{2b}{2b-i}$$

Luck matters too ☺ ☺ ☺

# Checkpointing

No Replication $$T_{opt} = \sqrt{2\mu_N C} \quad (4)$$

Full Replication $$T_{opt} = \sqrt{2M_N C} \quad (5)$$

# What's Wrong?

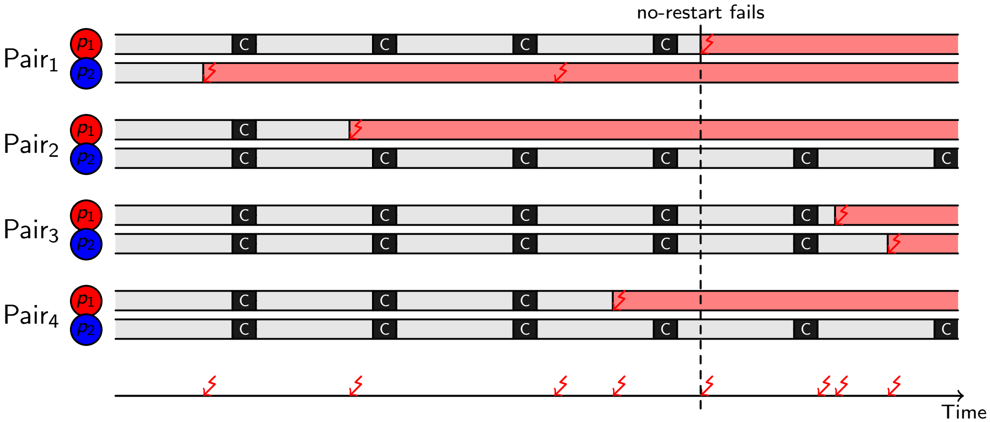
$$T_{opt} = \sqrt{2 M_N C}$$

- Just an approximation. How accurate?
- Risk is increasing as more and more processors die until application crash
  $\Rightarrow$ Periodic checkpointing (most likely) not optimal ☹

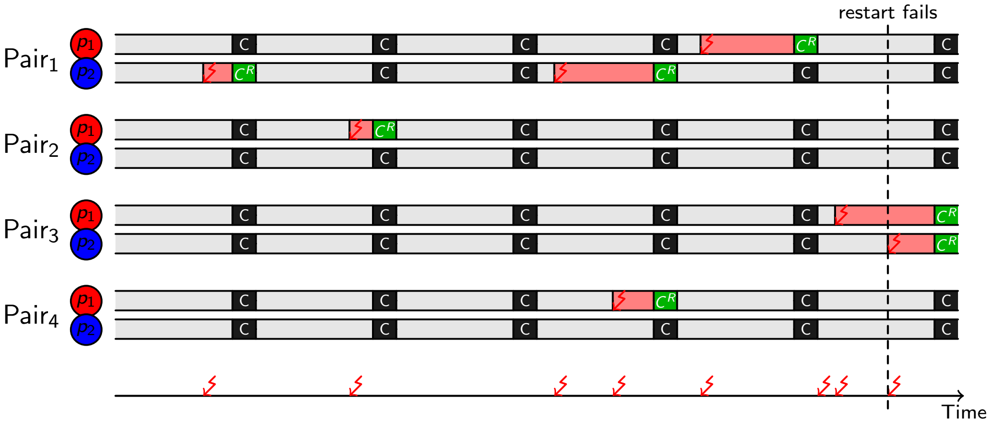
# Outline


1. Replication
2. New Strategy
3. Digression
4. Experiments

# *no-restart* vs. *restart*



# *no-restart* vs. *restart*



## restart

- Restart all failed processors (if any) after each checkpoint instead of only after interruption
- What is the additional cost?
- What is the optimal checkpointing period?

# Combined Checkpoint-Restart

**Cost of a checkpoint and restart wave $C^R$**

- one instance of each surviving process saves state (checkpoint)
- processes for missing replicas of the replicas allocated
- new processes load current (checkpointed) state and join system

**In-memory checkpoint replication**

- the buddy process and the replica are the same process
- surviving processes upload their checkpoint directly onto memory of newly spawned replicas

$\Rightarrow$ no exchange of checkpoints between pair of surviving buddies

**Worst case**: sequential approach, $C^R = 2C$
**Best-case**: buddy checkpointing, negligible overhead, $C^R \approx C$

# Checkpointing Period

Periodic checkpointing is optimal for *restart*

$$T^{\text{rs}}_{opt} = \left(\frac{3C^R}{4b\lambda^2}\right)^{\frac{1}{3}} = \Theta(\lambda^{-\frac{2}{3}}). \quad (6)$$

$$\mathbb{H}^{\text{rs}}(T^{\text{rs}}_{opt}) = \left(\frac{3C^R\sqrt{b}\lambda}{\sqrt{2}}\right)^{\frac{2}{3}} + o(\lambda^{\frac{2}{3}}) = \Theta(\lambda^{\frac{2}{3}}) \quad (7)$$

An order of magnitude longer!

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# Single Processor Pair

One processor: $T_{YD} = \sqrt{2\mu C}$

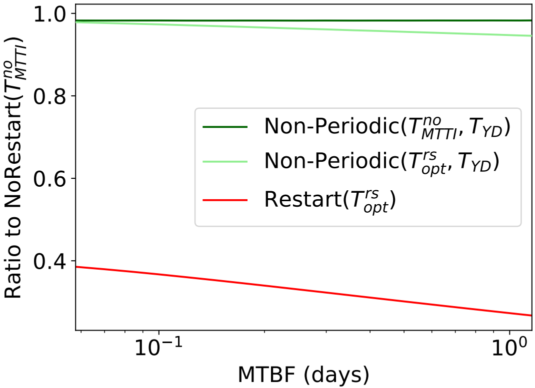
One replica pair, *no-restart*: $\mu_2 = \frac{\mu}{2}$, $n_{\text{fail}}(2) = 3$, $T^{\text{no}}_{MTTI} = \sqrt{3\mu C}$

One replica pair, *restart*: $T^{\text{rs}}_{opt} = \left(\frac{3}{4}C\mu^2\right)^{\frac{1}{3}}$

**Four variants**:

- *no-restart* ($T^{\text{no}}_{MTTI}$): baseline
- *restart* ($T^{\text{rs}}_{opt}$): check how good we are
- *no-restart* NonPeriodic($T_1$, $T_2$):
  - use $T_1$ while both processors are alive
  - switch to $T_2$ after first failure
    - Variant 1: $T_1 = T^{\text{no}}_{MTTI}$, $T_2 = T_{YD}$
    - Variant 2: $T_2 = T^{\text{rs}}_{opt}$, $T_2 = T_{YD}$
- 100,000 simulations, each with 10,000 periods

# Single Processor Pair




Ratio of time to solution of two non-periodic strategies and *restart* over time-to-solution of *no-restart* ($C = C^R = 60$ seconds)

# Outline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4. Experiments
   - Overhead
   - Time To Solution
   - When To Restart

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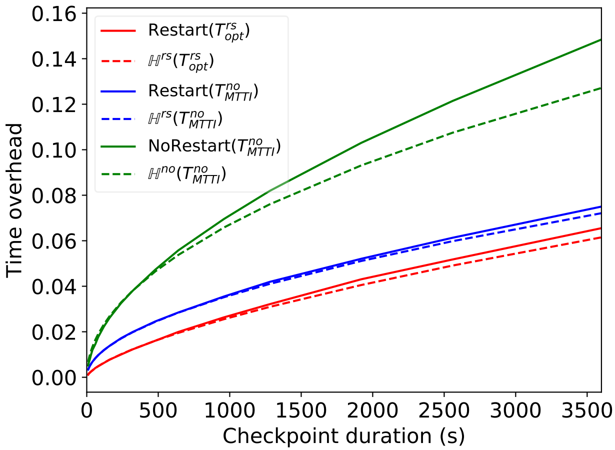
# Notations

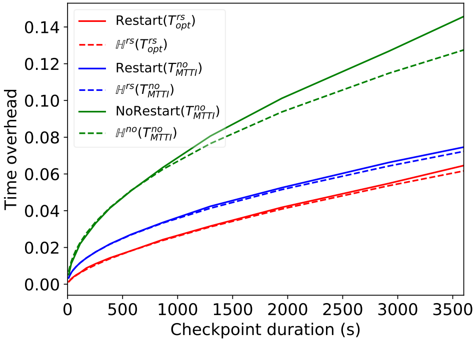
- *restart*
  $Restart(T)$ and overhead $\mathbb{H}^{\mathrm{rs}}(T)$
  $T^{\mathrm{rs}}_{opt}$ optimal period
- *no-restart*
  $NoRestart(T)$ and overhead $\mathbb{H}^{\mathrm{no}}(T)$
  $T^{\mathrm{no}}_{MTTI}$ used as 'optimal' period (analogy with Young/Daly)

# Model Accuracy

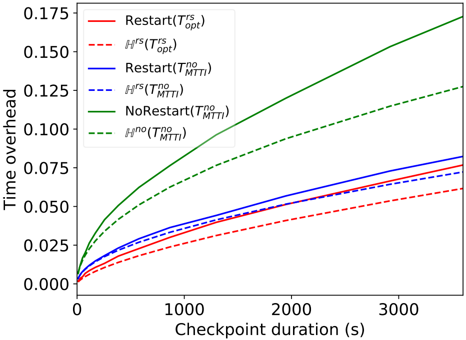



$\mu = 5$ years, $b = 10^5$ processor pairs, $C^R = C$

# Model Accuracy With Trace Logs



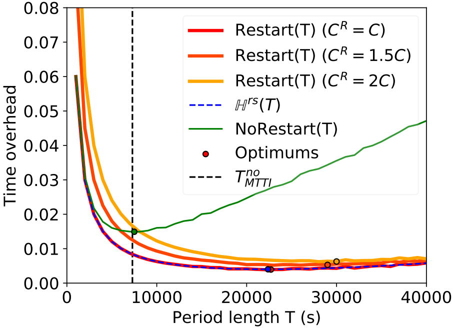

LANL#18

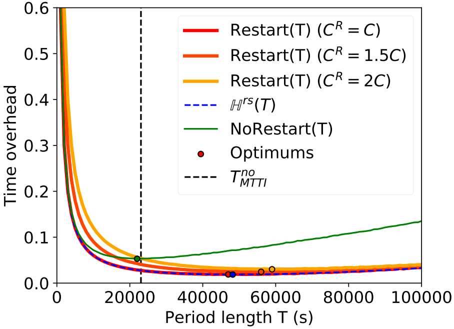



LANL#2

$$\mu = 5 \text{ years}, \; b = 10^5 \text{ processor pairs}, \; C^R = C$$

# Impact of Checkpointing Period



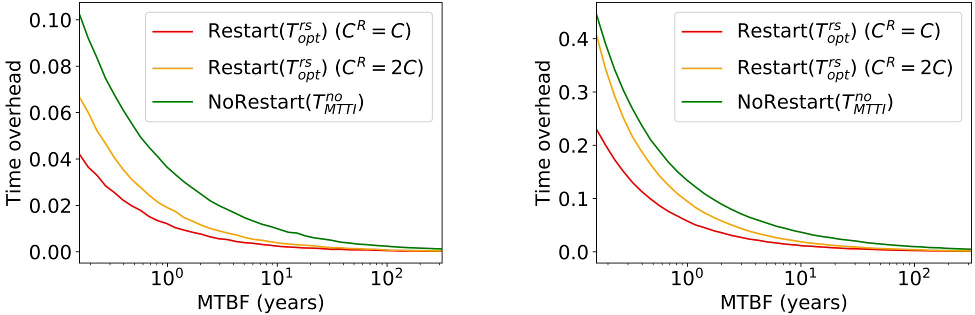




$C = 60$ seconds

$C = 600$ seconds

$\mu = 5$ years, $b = 10^5$ processor pairs

# Impact of MTBF

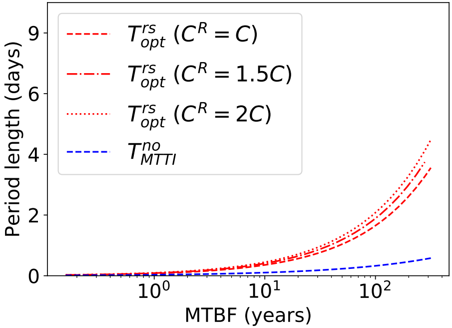



$C = 60$ seconds

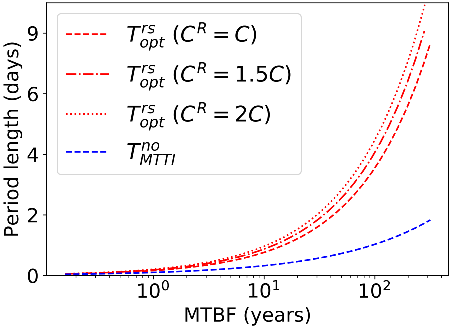
$C = 600$ seconds

$b = 10^5$ processor pairs

# I/O Pressure




$C = 60$ seconds




$C = 600$ seconds

$b = 10^5$ processor pairs

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- Overhead
- Time To Solution
- When To Restart

# Time To Solution

**No replication, $N$ parallel processors**

$$T_{final} = (\mathbb{H}_{opt} + 1)\left(\gamma + \frac{1-\gamma}{N}\right) T_{seq}, \qquad \mathbb{H}_{opt} = \sqrt{\frac{2C}{\mu_N}}$$

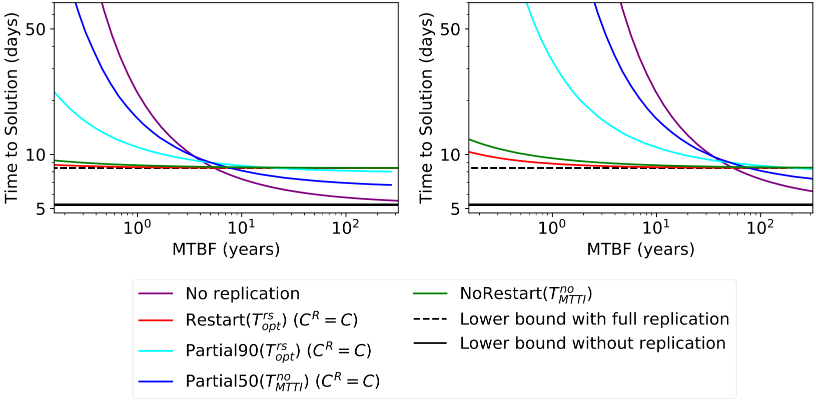
**Replication, $N = 2b$, $b$ replica pairs**

$$T_{final} = (\mathbb{H}_{opt} + 1)(1+\alpha)\left(\gamma + \frac{2(1-\gamma)}{N}\right) T_{seq}$$

*no-restart* $\mathbb{H}_{opt} = \sqrt{\frac{2C}{M_N}}$

*restart* $\mathbb{H}_{opt} = \left(\frac{3C^R\sqrt{N}\lambda}{2\mu}\right)^{\frac{2}{3}}$

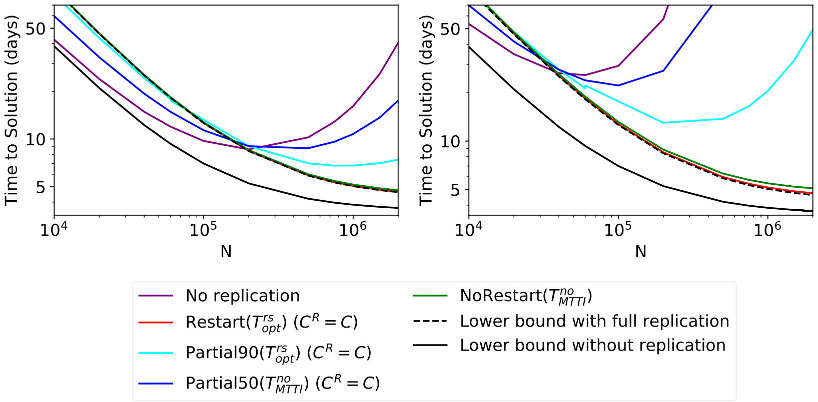
# Time To Solution




$C^R = C = 60$ seconds $\quad C^R = C = 600$ seconds

$N = 200,000,\ \gamma = 10^{-5},\ \alpha = 0.2$

# Replication Useful?




$C^R = C = 60$ seconds $\quad C^R = C = 600$ seconds

$\mu = 5$ years, $\gamma = 10^{-5}$, $\alpha = 0.2$

# Outline

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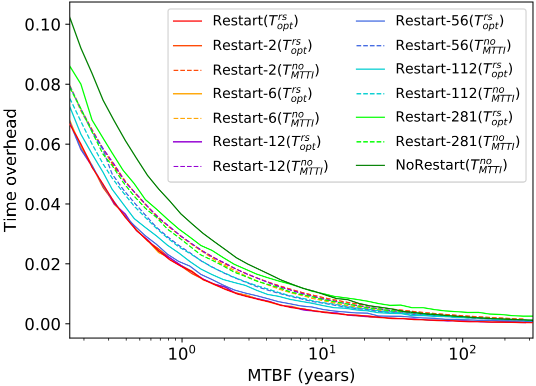
# When To Restart




$C^R = C = 60$ seconds, $b = 10^5$ and $n_{\text{fail}}(2b) = 561$

# Summary

- Model is realistic ☺
- *restart* with $T^{\text{rs}}_{opt}$ is indeed optimal ☺
- Smaller time overheads than *no-restart* with $T^{\text{no}}_{MTTI}$, longer periods, less I/O pressure ☺ ☺ ☺

# Conclusion

- Opinion is divided about replication
- Checkpoint/restart alone cannot ensure full reliability in heavily failure-prone environments
- When replication is needed (large $C$, short $\mu$, large $\gamma$), magic recipe:
  - use full replication
  - *restart* dead processors at each checkpoint (overlap if possible)
  - use $T_{opt}^{\text{rs}}$

## Future Work

Solve the non-periodic problem with one replica pair
. . . so that we can sleep again !!!!!!!!!! ☺ ☺ ☺

Experimentally evaluate non-periodic checkpointing strategies that rejuvenate failed processors after a given number of failures is reached or after a given time interval is exceeded

Revisit partial replication for heterogeneous platforms

# Comment trouver des problèmes de recherche rigolos ?

- Broder sur les règles du jeu, en cherchant à avoir un modèle réaliste
- Trouver des instances du problème de complexité non triviale (notamment pour le placement de répliques)
- Partir de problèmes existants, de papiers trouvés dans la littérature qui traitent de sujets de recherche encore ouverts
- Discuter avec ses collègues, son directeur de thèse !