# Υποθετικός Πολυνηματισμός

# Τα προβλήματα του παράλληλου προγραμματισμού

- Εντοπισμός παραλληλισμού
  - χειροκίνητα (επισκόπηση)
  - αυτόματα (compiler)
- Έκφραση παραλληλισμού
  - low-level (π.χ. Pthreads, MPI)
  - high-level (π.χ. OpenMP, Cilk, Intel TBB, Galois, UPC κ.λπ.)
- Απεικόνιση
  - scheduling, creation, termination, etc.
  - operating system, runtime system
- Συγχρονισμός
  - εύκολος όπως ο coarse-grain
  - αποδοτικός όπως ο fine-grain
  - deadlock-free
  - composable
- Απαιτήσεις
  - κλιμακωσιμότητα
  - ευκολία προγραμματισμού
  - υψηλή παραγωγικότητα
  - ορθότητα
  - architectural awareness

# Parallelizing Compilers

- Στοχεύουν σε «κανονικές» εφαρμογές
  - for loops, arrays
  - (παραδοασικά, HPC scientific codes…)
- Συνήθως, 2 περάσματα:
  - Είναι ένα loop «ασφαλές» για παραλληλοποίηση;
    - στατική ανάλυση (dependence, alias)
  - «Αξίζει» να παραλληλοποιηθεί;
    - cost model, profiling
  - Παραδείγματα: Intel CC, SUIF-1, Polaris, PGI, Open64

- Τι γίνεται με τις «ακανόνιστες» εφαρμογές;
  - ασαφείς/μη-σταθερές εξαρτήσεις (π.χ. input dependent)
  - «περίπλοκες» δομές

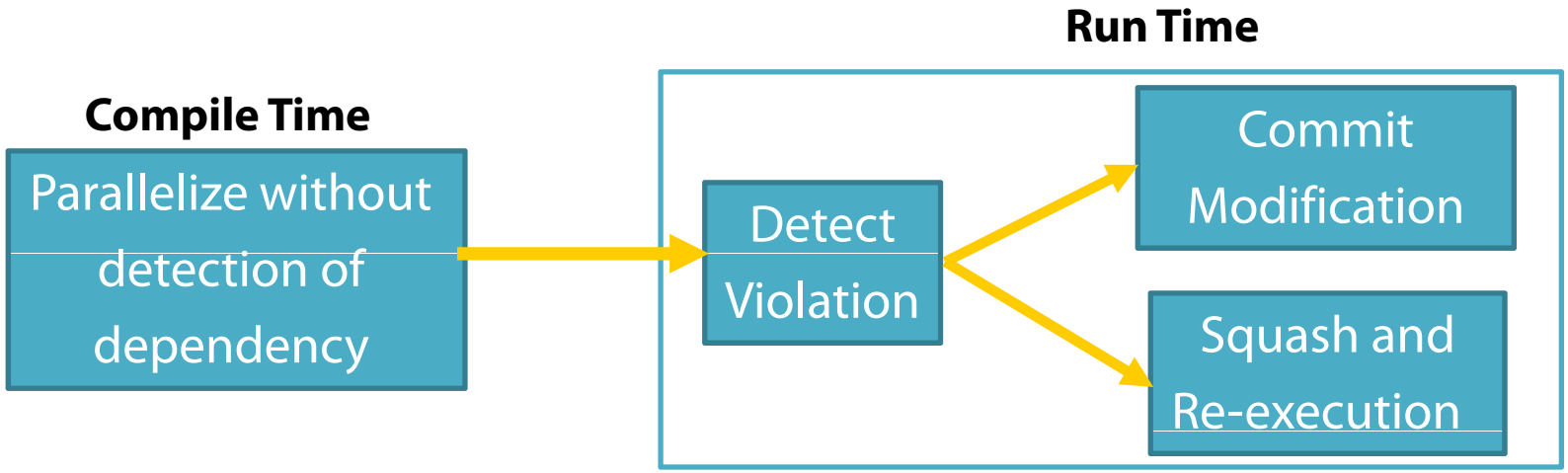
# Ενδεικτική κατηγοριοποίηση

| **Χαρακτηριστικά κώδικα** | **Παράδειγμα** | **Πεδίο εφαρμογής** |
|---|---|---|
| Arrays with direct addressing | for(i = 1; i<n; i++) {<br>A[i] = B[i]*C[i];<br>} | • scientific codes<br>• media applications |
| Arrays with indirect addressing | for(i = 1; i<n; i++) {<br>z = A[K[i]];<br>A[L[i]] = z + C[i];<br>} | • circuit simulations<br>• structural mechanics modeling<br>• molecular dynamics simulation<br>• fluid flows |
| Recursive Data Structures (RDS):<br>• trees<br>• lists<br>• graphs<br>• sets<br>• hash-tables<br>• … | while(ptr=ptr->next) {<br>ProcessElement(ptr->val);<br>} | • graph algorithms (shortest paths, minimum spanning trees, max flows)<br>• simulations (N-body, graphics)<br>• meshes (refinement, triangulation)<br>• dynamic programming<br>• data mining<br>• … |

# Υποθετικός Πολυνηματισμός

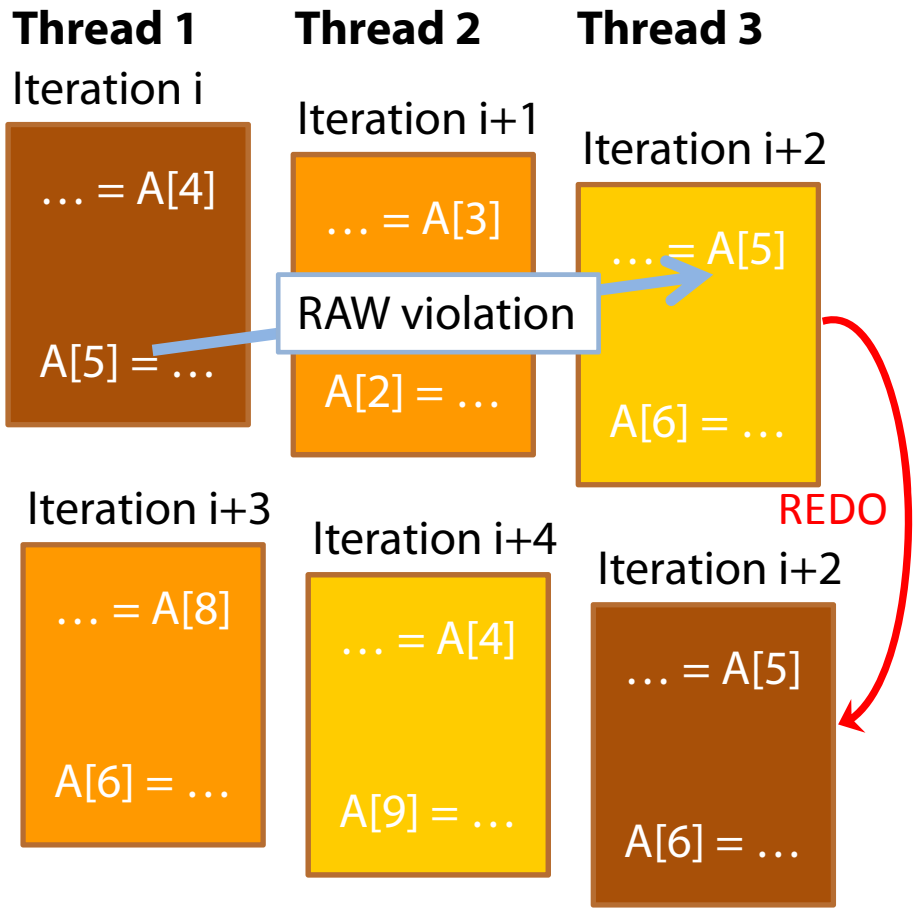
Speculative Multithreading or Thread-Level Speculation

- επιτρέπει τη δημιουργία και εκτέλεση παράλληλων νημάτων παρά τις πιθανές εξαρτήσεις δεδομένων
- ελπίζουμε στην μη-ύπαρξη εξαρτήσεων
  - «αισιόδοξος» παραλληλισμός



# Παράδειγμα

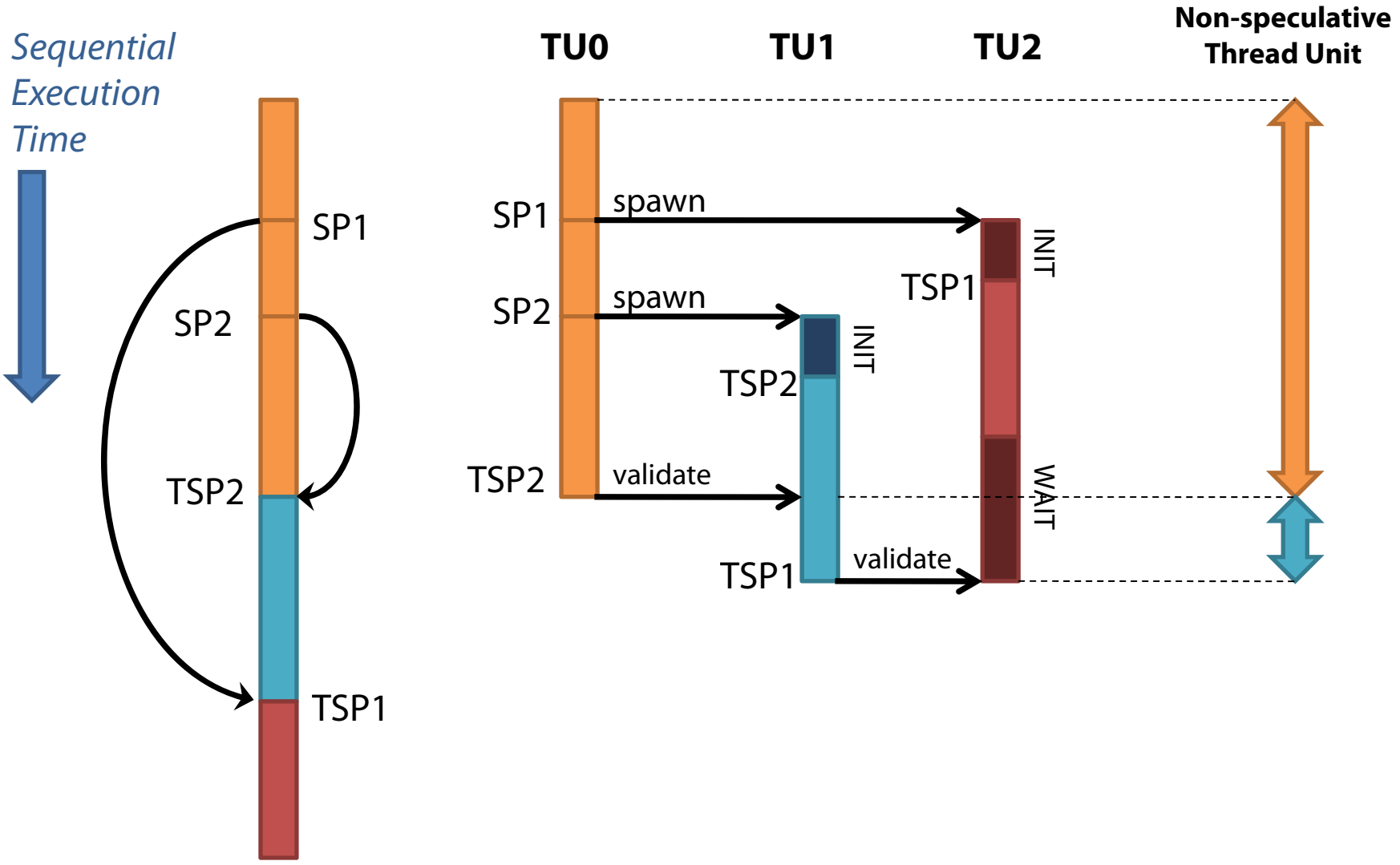
```
for(i=0; i<n; i++) {
    … = A[B[i]];
    …
    A[C[i]] = …
}
```



# Γενικό Μοντέλο

- 1 main (non-speculative) thread
  - γηραιότερο
  - το μόνο που επιτρέπεται να κάνει commit
- N ≥ 0 speculative threads
- σχέσεις predecessor-successor ανάμεσα στα threads
  - sequential semantics
- οποιοδήποτε thread μπορεί να κάνει spawn κάποιο άλλο (speculative) thread

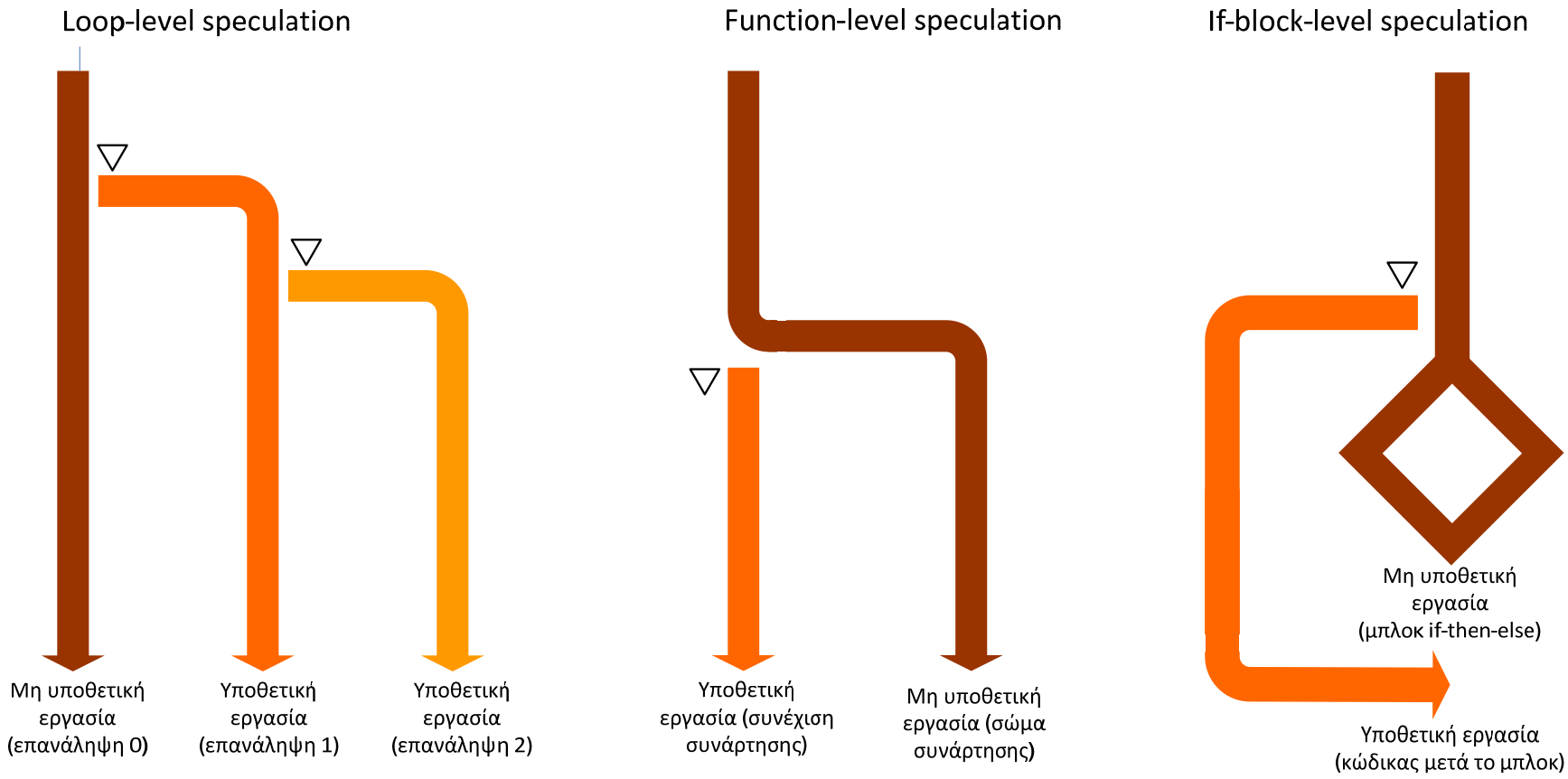
# Γενικό Μοντέλο




SP: spawning point
TSP: thread start point

# Προγραμματιστικές Δομές

- ξεκινάμε από το σειριακό πρόγραμμα και εξάγουμε «ordered» νήματα (ή εργασίες )



# Υποθετικός Πολυνηματισμός

Το HW/SW (runtime system) παρέχει υποστήριξη για:

- checkpointing των καταχωρητών στην αρχή της εκτέλεσης μιας εργασίας
- buffering της υποθετικής κατάστασης που δημιουργείται
  - π.χ. write-buffer, cache
- παρακολούθηση των λειτουργιών μνήμης των εργασιών
  - παραβίαση εξαρτήσεων: αναίρεση των επιδράσεων της (πιο) υποθετικής εργασίας και επανεκκίνηση
    - π.χ. απόρριψη write-buffer, restore registers
  - μη παραβίαση εξαρτήσεων: commit αποτελεσμάτων των εργασιών
    - στη σειρά προγράμματος!

# Παράδειγμα Ανίχνευσης Παραβιάσεων

- Επέκταση cache με
  - timestamp («epoch number»): δείχνει τη σειρά στο σειριακό πρόγραμμα
  - violation flag
- Επέκταση cache line με ειδικά bits
  - SL: κάποιο speculative load έχει προσπελάσει την cache line
  - SM: η γραμμή έχει τροποποιηθεί υποθετικά
- Σε κάθε write-invalidation, μια εργασία μαρκάρεται για ακύρωση αν:
  - η γραμμή είναι παρούσα στην cache της
  - το SL bit της είναι set
  - το «epoch number» του invalidator υποδεικνύει προγενέστερο νήμα στη σειρά προγράμματος

# Παράδειγμα Ανίχνευσης Παραβιάσεων

**Processor 1**
**Epoch 5**

…

②**STORE *q = 2;**

…

**L1 Cache**

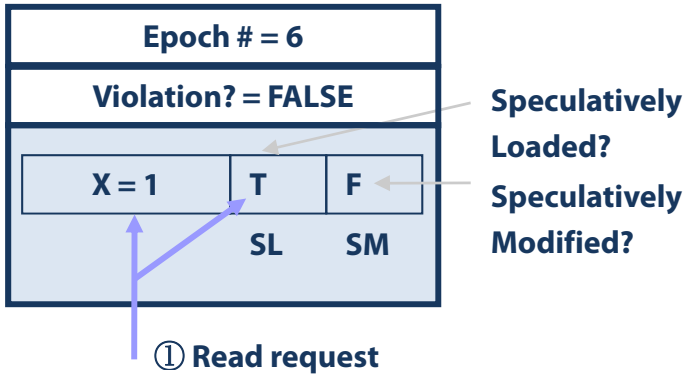
| Epoch # = 5 |
| --- |
| Violation? = FALSE |
| |

**p = q = &x**

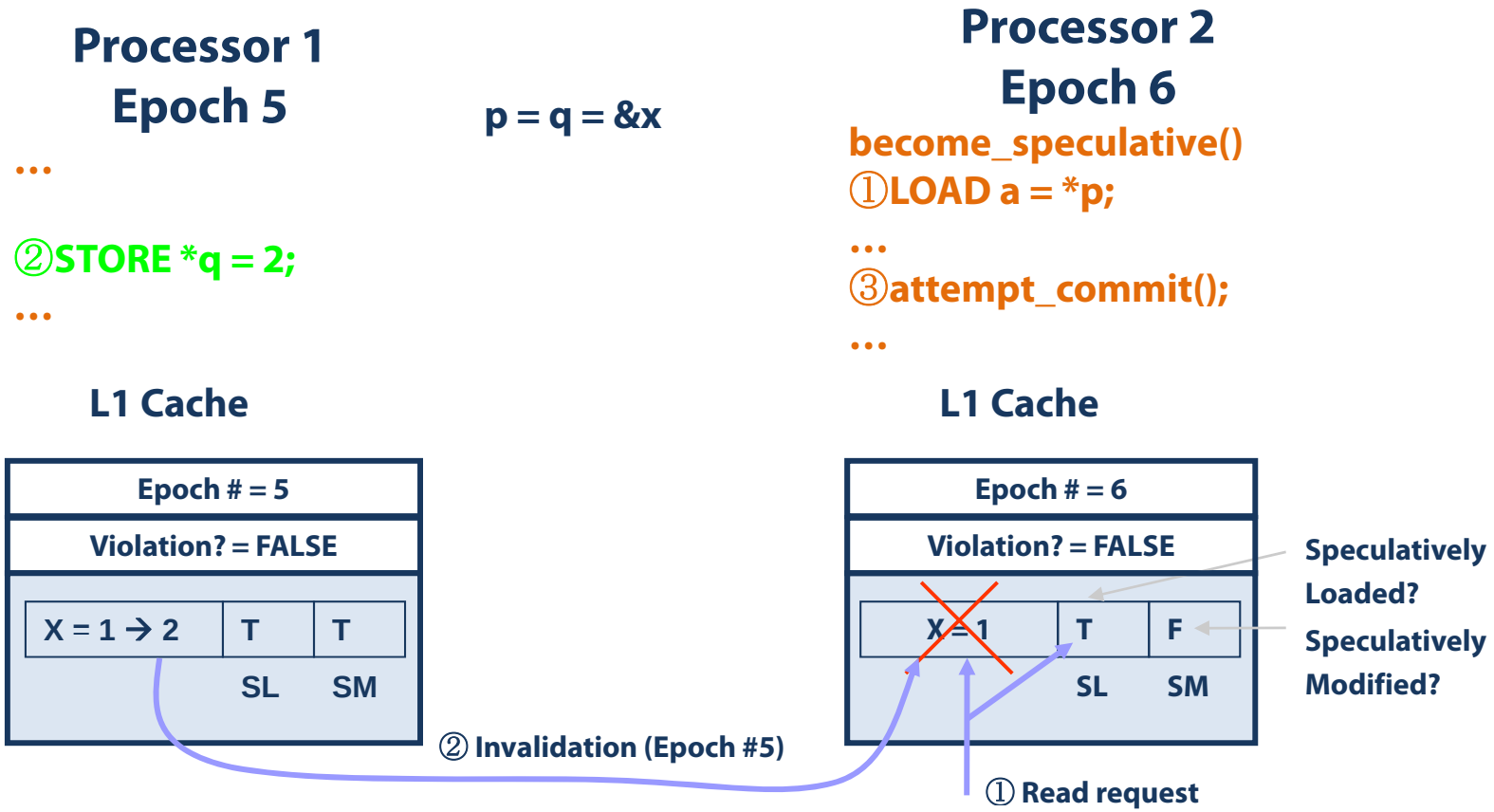
**Processor 2**
**Epoch 6**

**become_speculative()**
①**LOAD a = *p;**
…
③**attempt_commit();**
…

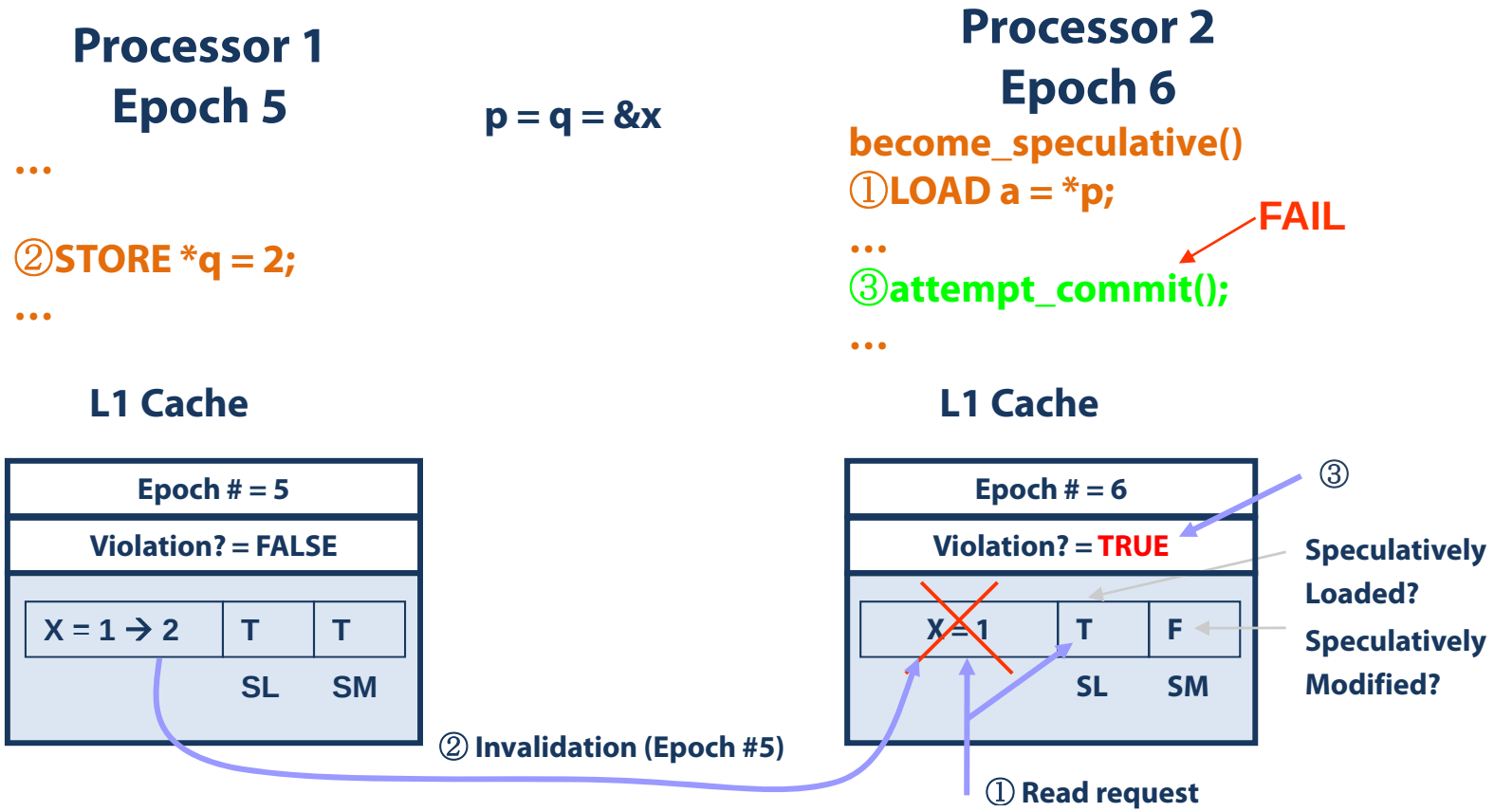
**L1 Cache**



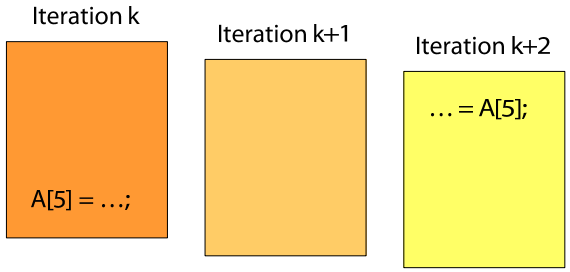
# Παράδειγμα Ανίχνευσης Παραβιάσεων



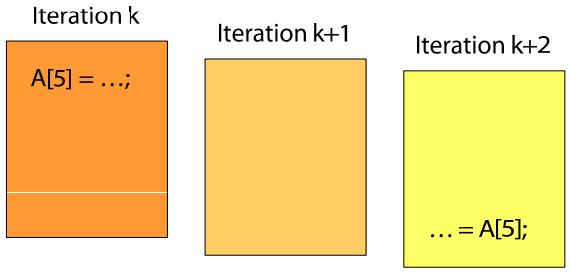
# Παράδειγμα Ανίχνευσης Παραβιάσεων



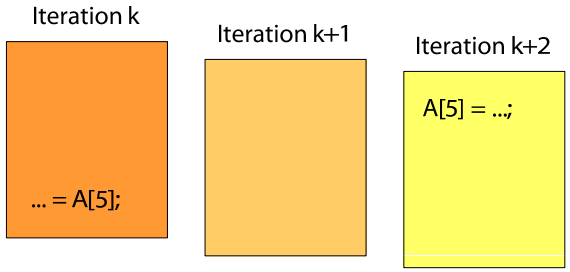
# Τι εξαρτήσεις μας νοιάζουν τελικά;



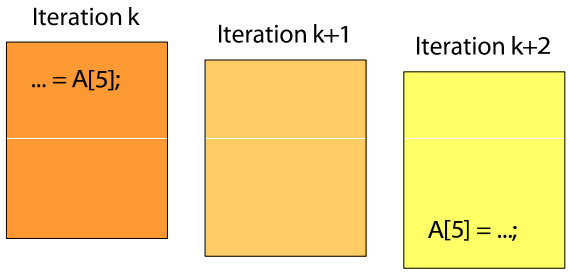

**RAW** dependence violated:
violates sequential semantics (k's store should have preceded k+2's load in program order)




**RAW** dependence respected:
no problem (theoretically), but requires data forwarding mechanism



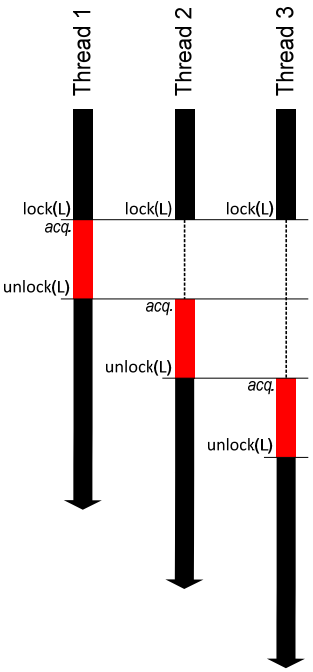

**WAR** dependence violated:
no problem if speculative writes are being buffered

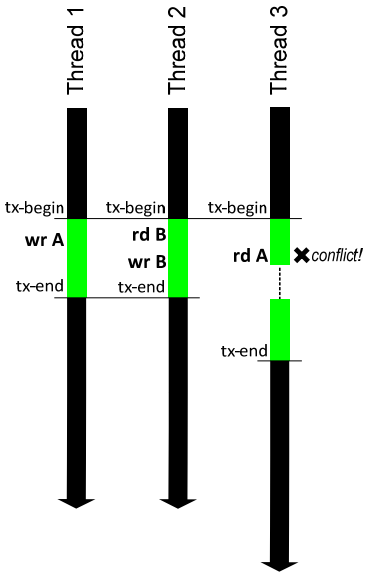



**WAR** dependence respected:
no problem

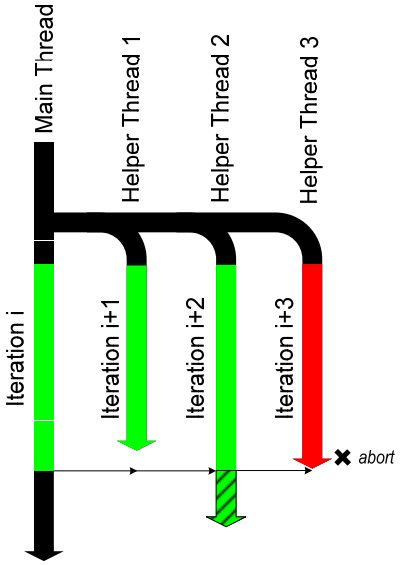
# TM vs TLS

- αισιόδοξος συγχρονισμός

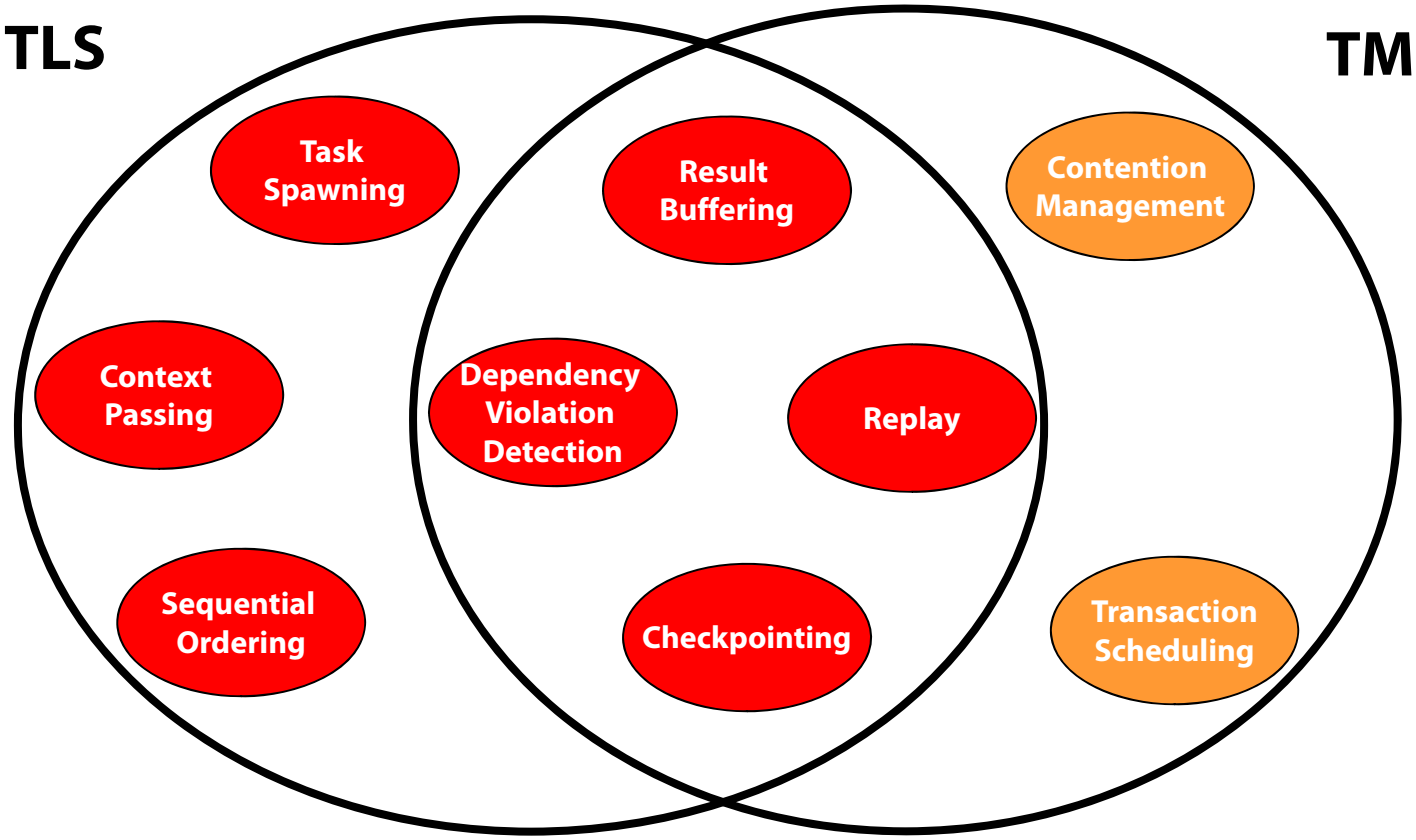



- αισιόδοξος *παραλληλισμός*

# TM vs TLS




**TLS and TM share multiple hardware components**

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