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computer languages

Durability and Contention in Software Transactional Memory

Masterstudium:
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Software Transactional Memory

Software Transactional Memory (STM) vastly simplifies concurrent programming by grouping memory operations into atomic blocks.

The following Haskell function increments a transactional variable and returns its previous contents:

$$\begin{aligned}&\textbf{inc}\ v = \ \textbf{do}\ x \leftarrow \textbf{readTVar}\ v\\ &\qquad\qquad\quad\ \textbf{writeTVar}\ v\ (x+1)\\ &\qquad\qquad\quad\ \textbf{return}\ x\end{aligned}$$

To perform an STM computation and make its effects visible to the system, the function **atomically** :: **STM** $a \rightarrow$ **IO** a is used:

atomically (**inc** v)

Problem 1: Durability

Manipulating memory using STM is easy, but persisting those manipulations in a transactionally safe way is impossible.

Two obvious but unsafe ways of trying to add durability to STM:

1. **do** $x \leftarrow$ **atomically** m
   serialize x

   Problem: serialization might fail after transaction committed

2. **atomically** \$ **do** $x \leftarrow m$
   unsafeIOToSTM (**serialize** x)

   Problem: transaction might abort or retry after serialization

STM Finalizers

Introduce a new STM primitive

atomicallyWithIO :: **STM** $a \rightarrow (a \rightarrow$ **IO** $b) \rightarrow$ **IO** b

which is like **atomically**, but additionally takes a *finalizer* — an I/O action that can depend on the result of the STM computation.

The finalizer is combined with the STM transaction such that:

1. The finalizer is only run if the transaction is guaranteed to commit.
2. The transaction only commits if the finalizer finishes successfully.

$$\frac{M;\ \Theta, \{\} \overset{*}{\Rrightarrow} \texttt{return}\ N;\ \Theta', \Delta' \qquad F\ N;\ (\Theta \cup \Delta') \overset{*}{\rightarrow} \texttt{return}\ P;\ \hat{\Theta}}{\mathbb{P}[\texttt{atomicallyWithIO}\ M\ F];\ \Theta \rightarrow \mathbb{P}[\texttt{return}\ P];\ \Theta' \cup \hat{\Theta}}\ (ARET)$$

$$\frac{M;\ \Theta, \{\} \overset{*}{\Rrightarrow} \texttt{return}\ N;\ \Theta', \Delta' \qquad F\ N;\ (\Theta \cup \Delta') \overset{*}{\rightarrow} \texttt{throw}\ P;\ \hat{\Theta}}{\mathbb{P}[\texttt{atomicallyWithIO}\ M\ F];\ \Theta \rightarrow \mathbb{P}[\texttt{return}\ P];\ \hat{\Theta}}\ (ATHROW2)$$

the design is formalized by an operational semantics

- durability is now trivially possible:
  atomicallyWithIO m **serialize**
- more generally, finalizers enable interactive transactions
- potential foundation for a distributed STM
- http://github.com/mcschroeder/ghc

Problem 2: Contention

Many standard data structures, when used in a transactional setting, cause unreasonably high numbers of conflicts.

Consider **TVar** (**HashMap** a):

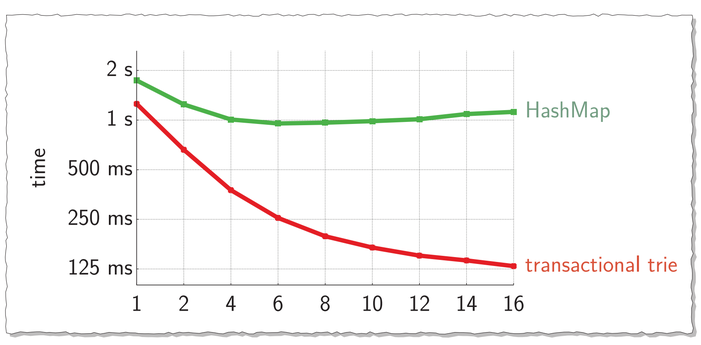
- any change to the container invalidates all other transactions
- but we should only care about the subset relevant to our transaction
- if transaction ***A*** updates element $\boldsymbol{k}_1$ and transaction ***B*** deletes element $\boldsymbol{k}_2$ and if $\boldsymbol{k}_1 \neq \boldsymbol{k}_2$, then there should be no conflict

Transactional Trie

The **transactional trie** is a new contention-free data structure, specifically tailored to the needs of transactional concurrency.

- based on the lock-free concurrent trie
- uses **unsafeIOToSTM** to perform atomic compare-and-swap operations independently of the surrounding STM transaction
- to preserve safety, leaves are stored as **TVar** (**Maybe** a)
- once a leaf is added, it is never removed

empirical evaluation of 200 000 random transactions on an Amazon EC2 C3 extra-large instance with 16 cores



- eliminates all spurious conflicts
- up to 8 times faster and using almost 10 times less memory
- http://hackage.haskell.org/package/ttrie

An example application using both finalizers and transactional tries to build a lightweight database framework on top of STM is available at http://github.com/mcschroeder/social-example

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