Scoped Values

A simple but powerful idea

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Original motivation, in brief

- Loom's Virtual Threads change the rules: threads are no longer scarce, but are limited only by memory
- When programs needs some sort of "current context", the standard Java way is to use a `ThreadLocal` variable
- But `ThreadLocal` doesn't scale at all well when we have millions of virtual threads, because every thread has its own set of the `ThreadLocal` objects it needs
- What if, instead of copying, we could share?
- It turned out that scoped values aren't just useful for Virtual Threads

Wider (prior) motivation, in brief

- **TL;DR** ThreadLocal does not promote well-structured programming
- No clean model for communicating data via a ThreadLocal
  - `get()` and `set()` can be called at any point during a Thread's lifetime
  - – potential for spaghetti dataflow up, down and across method invocation hierarchies
- No bounded lifetime for data managed via a ThreadLocal
  - A `get()` always returns some value (even if it might be null)
  - A `set()` value persists until the next set() or the end of the Thread lifetime
- Most programs would benefit from a simpler, more constrained solution
  - Which, it turns out, can also avoid the performance issues

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Let's see that in pictures . . .

Clean `ThreadLocal` use

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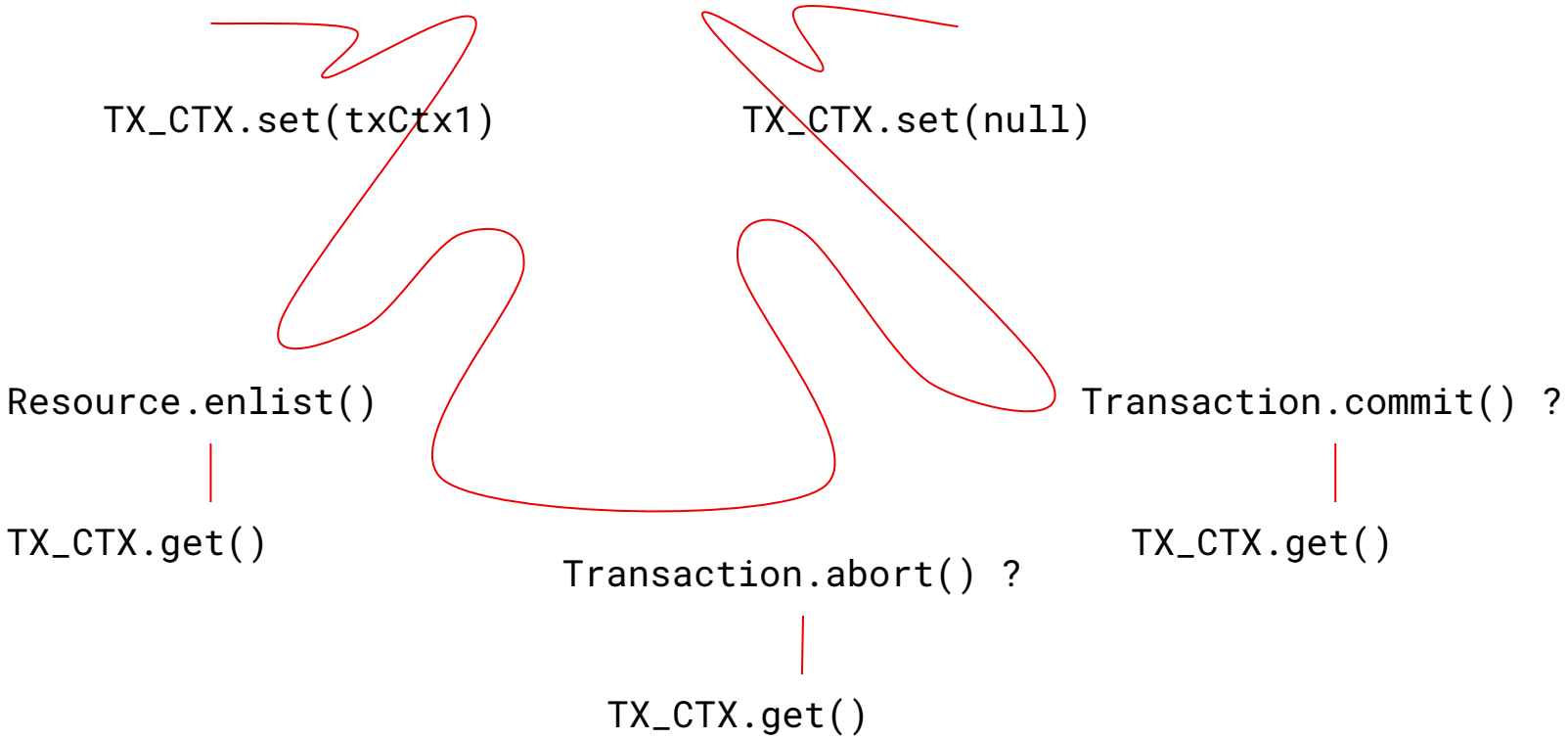
final static ThreadLocal<TransactionContext> TX_CTX = . . .;
```



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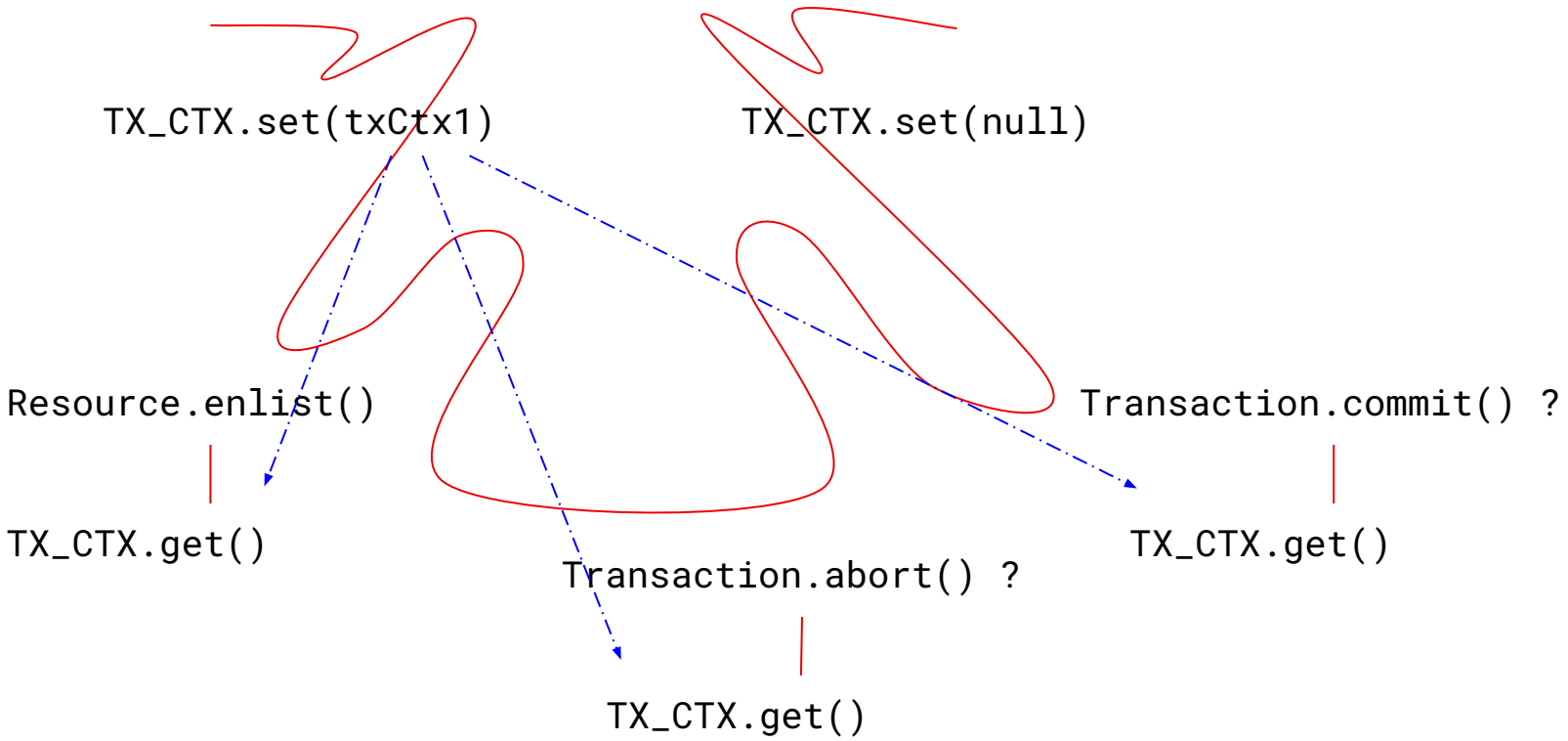

Clean `ThreadLocal` use (2)

```
final static ThreadLocal<GraphicContext> GR_CTX = . . .;
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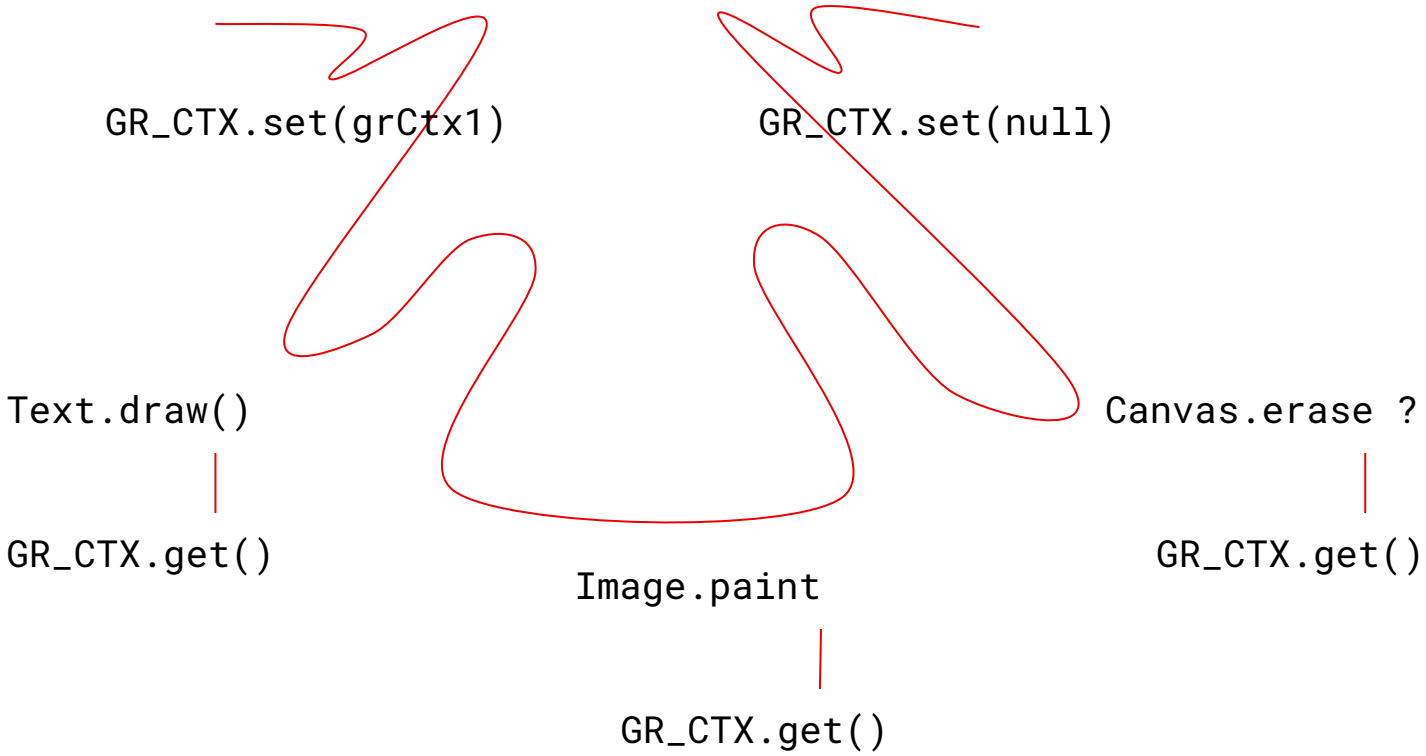

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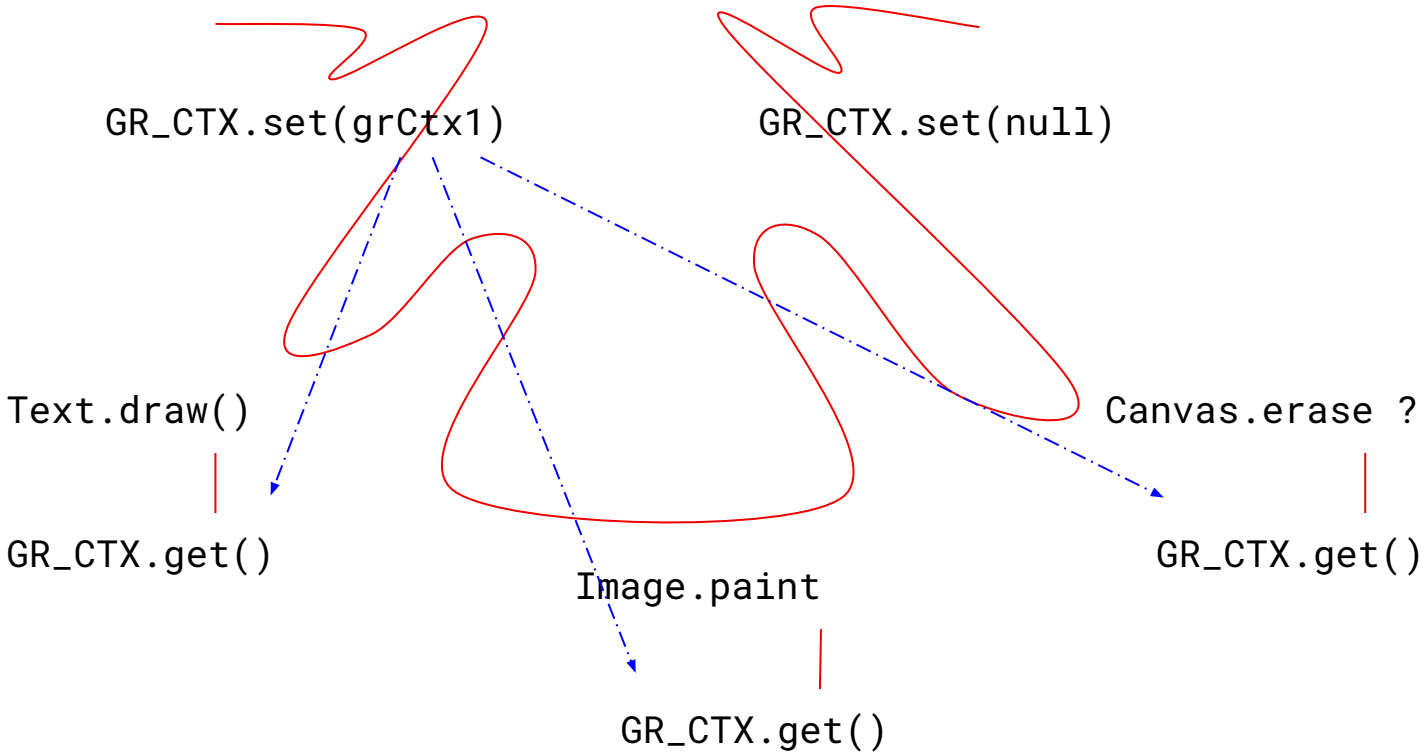

Clean `ThreadLocal` use (3)

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final static ThreadLocal<LogContext> LOG_CTX = . . .;
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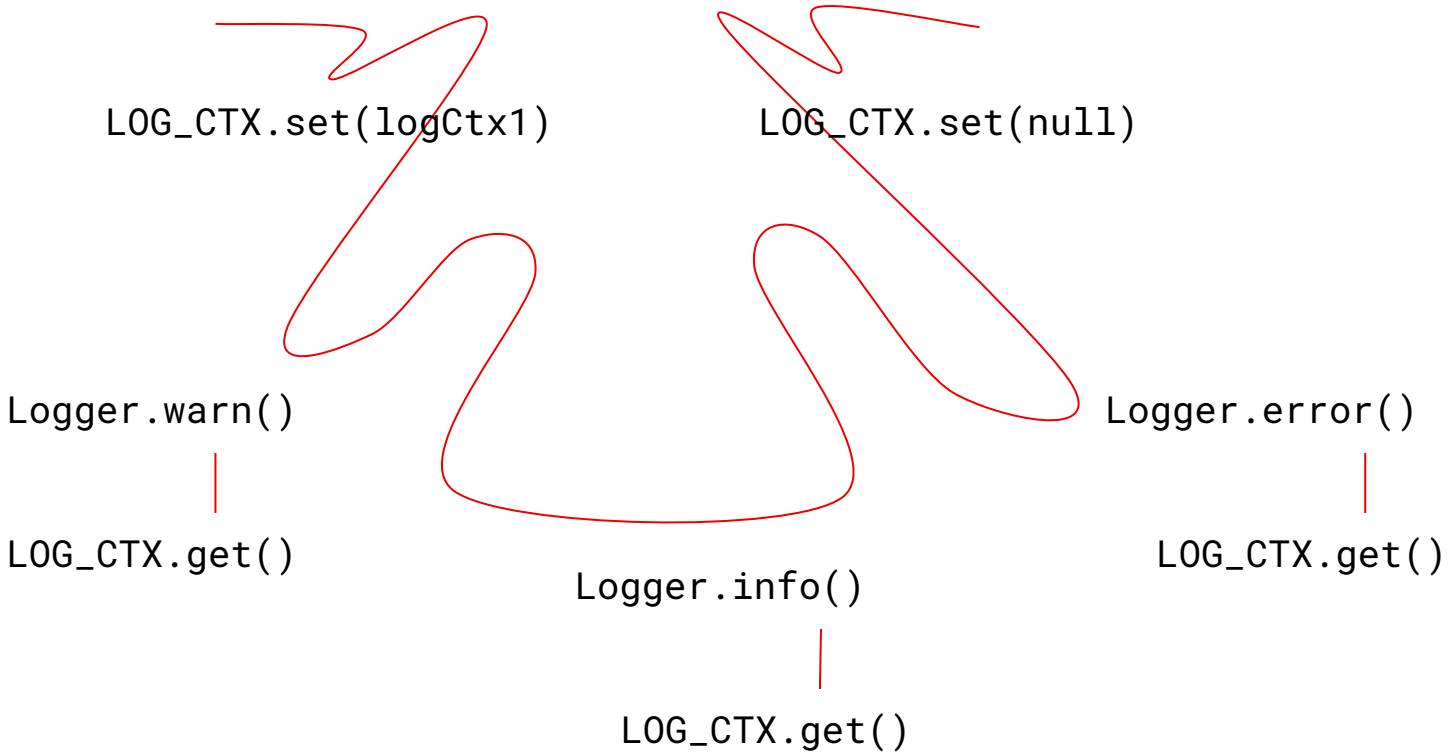

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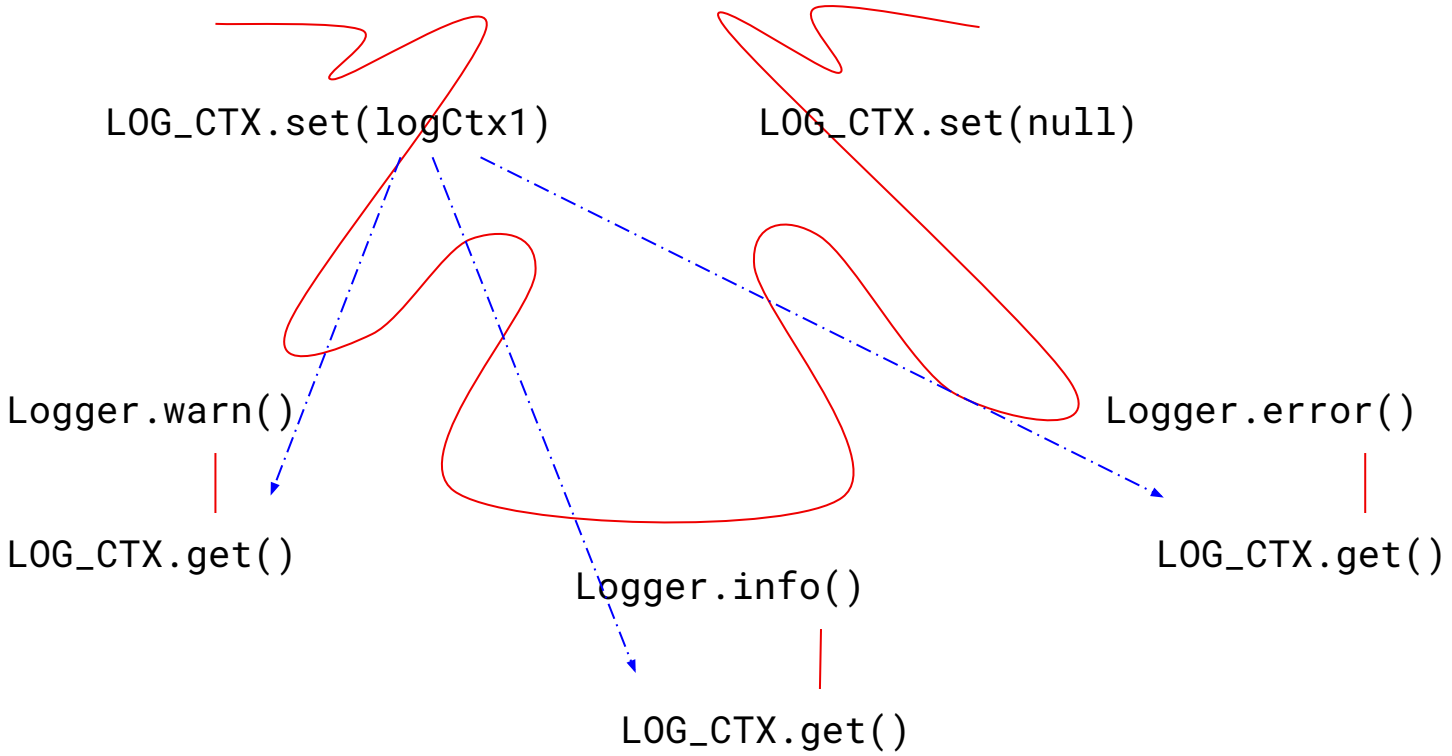

Common `ThreadLocal` use

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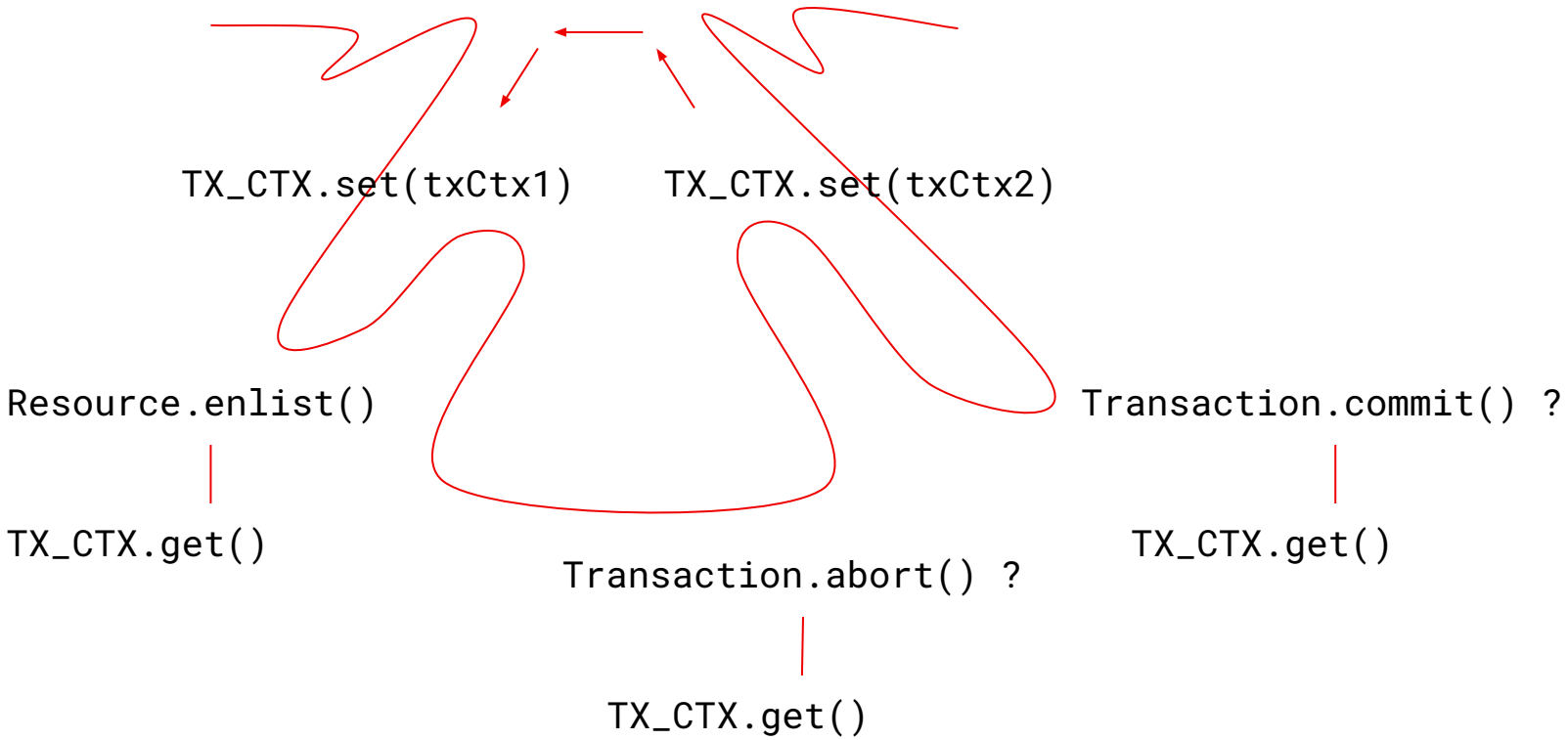

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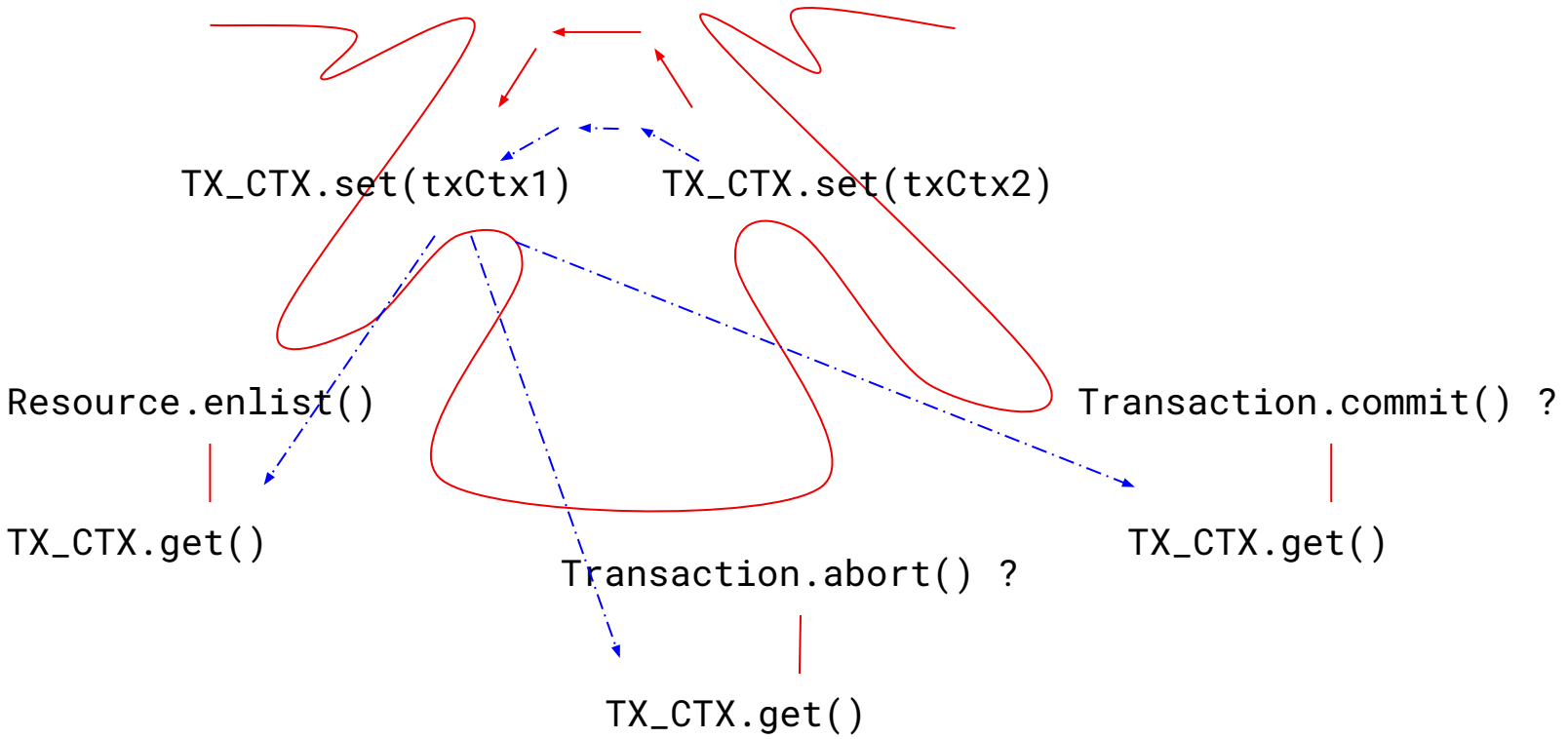

Worst(?) Case `ThreadLocal` use

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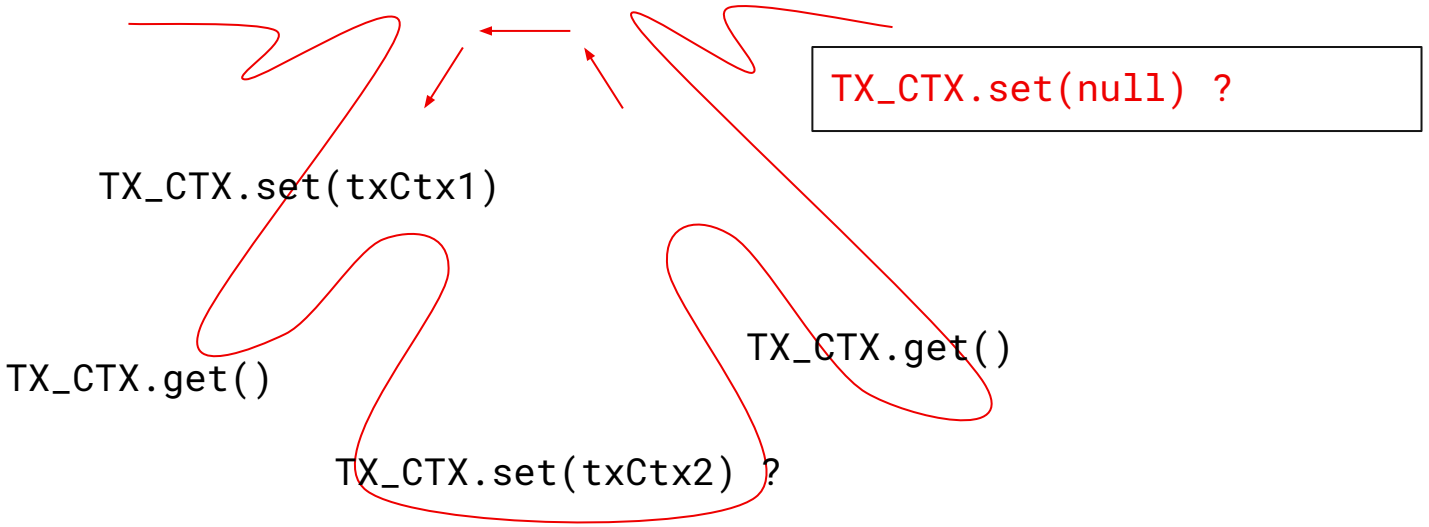

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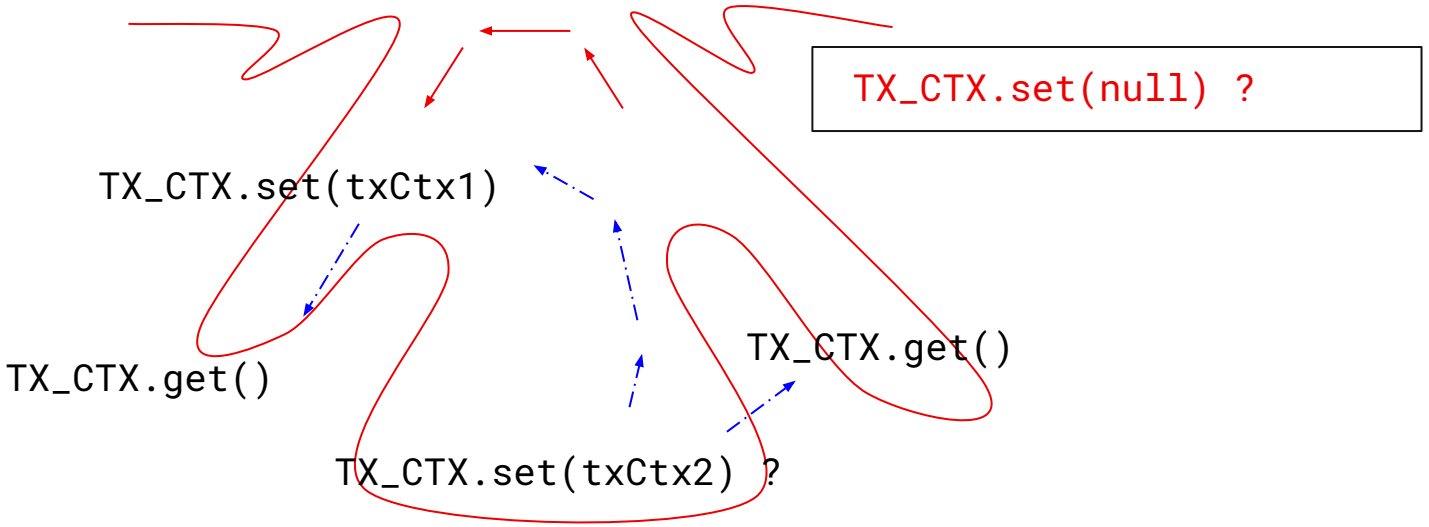

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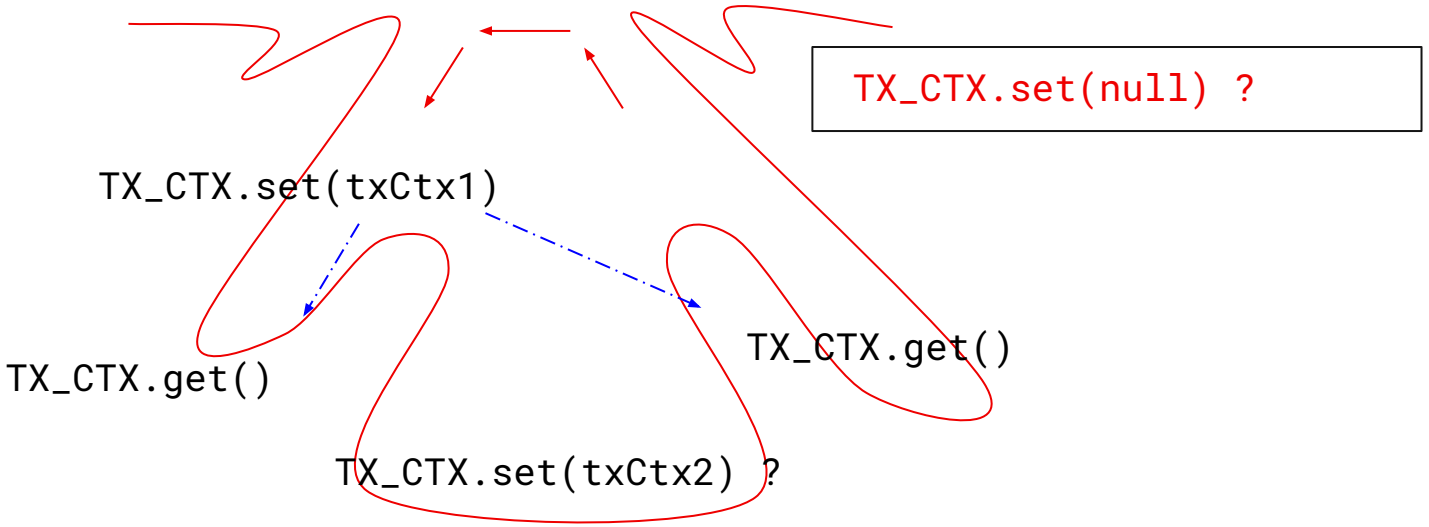

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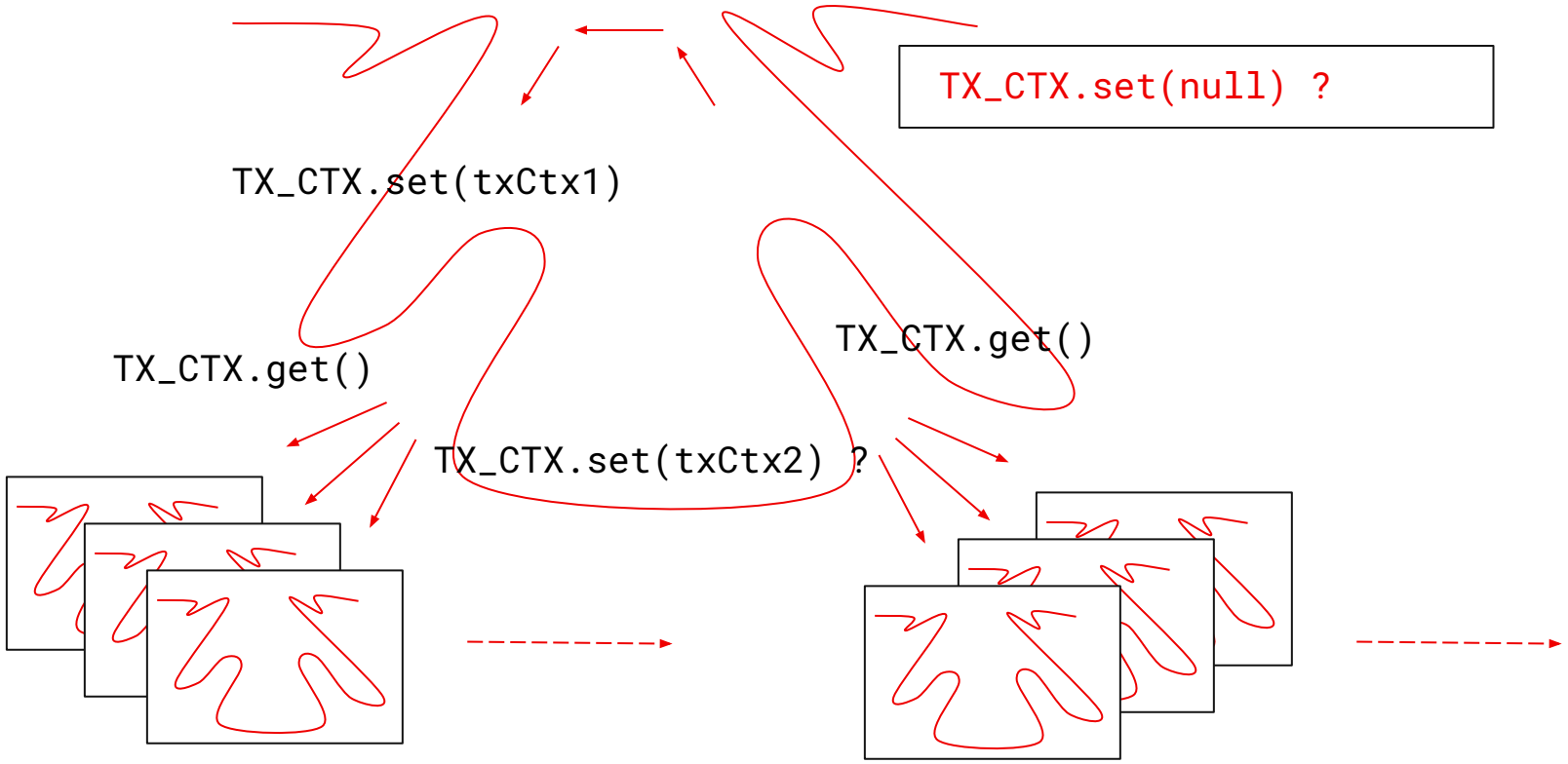

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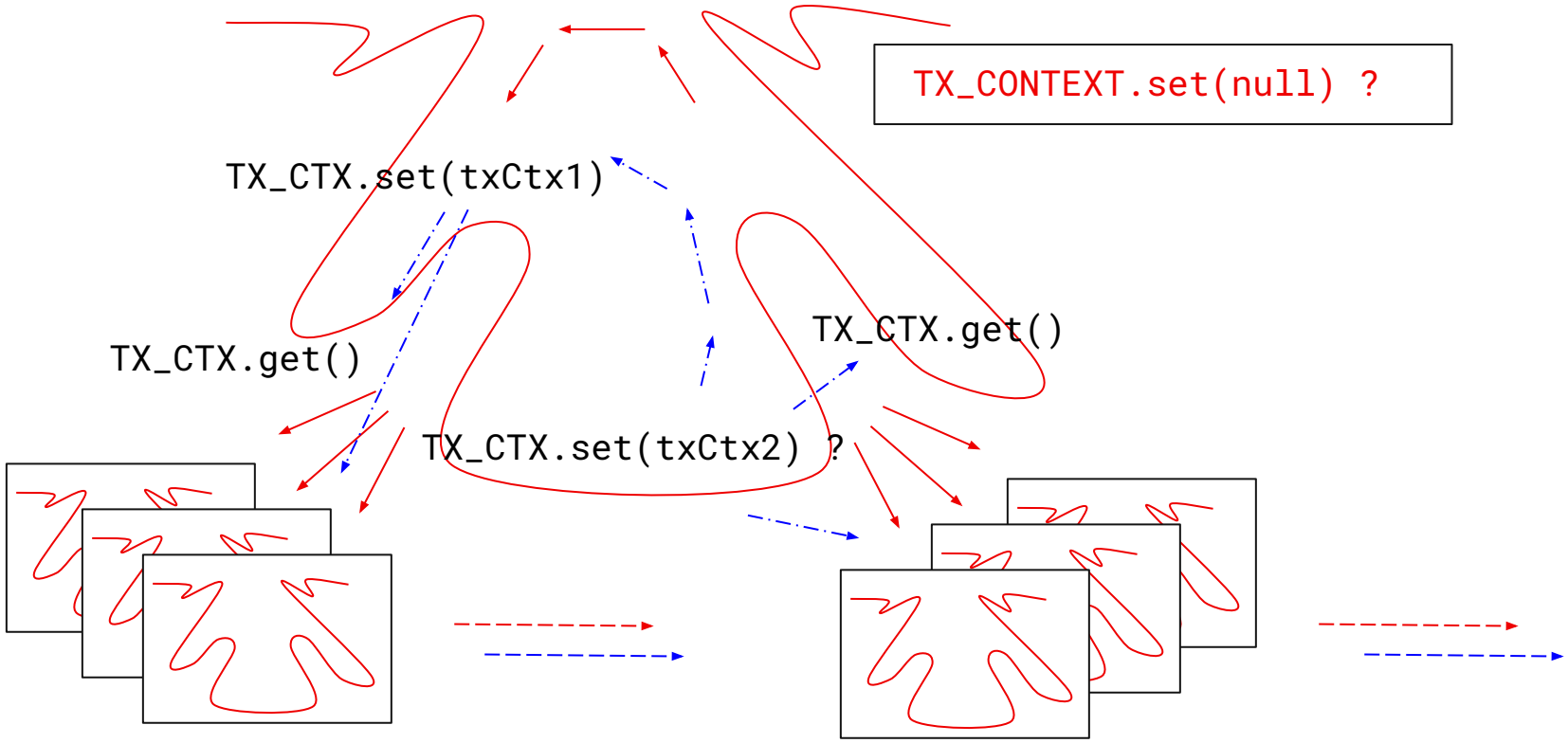

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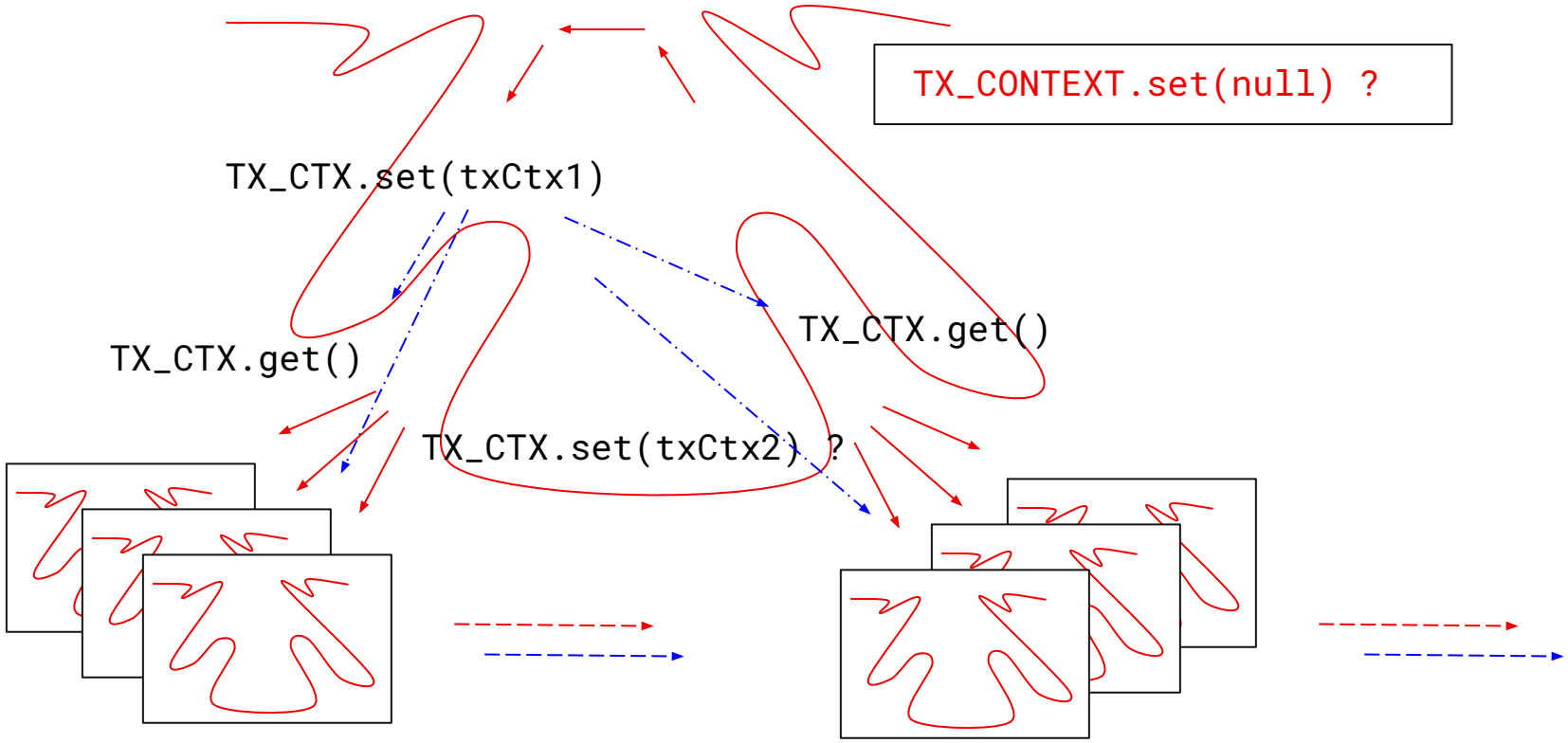

Scoped values: basic use model

In class `Transaction`:

```
static final
ScopedValue<TransactionContext> TX_CTX = ScopedValue.newInstance();
```

In some top-level server method:

```
Runnable task = () -> { serveRequest(...); }
TransactionContext txCtx = new TransactionContext(...);
ScopedValue.where(TX_CTX, txCtx).run(task);
```

In a method called directly or indirectly from `serveRequest`:

```
... TX_CTX.get() ...
```


Clean `ScopedValue` use

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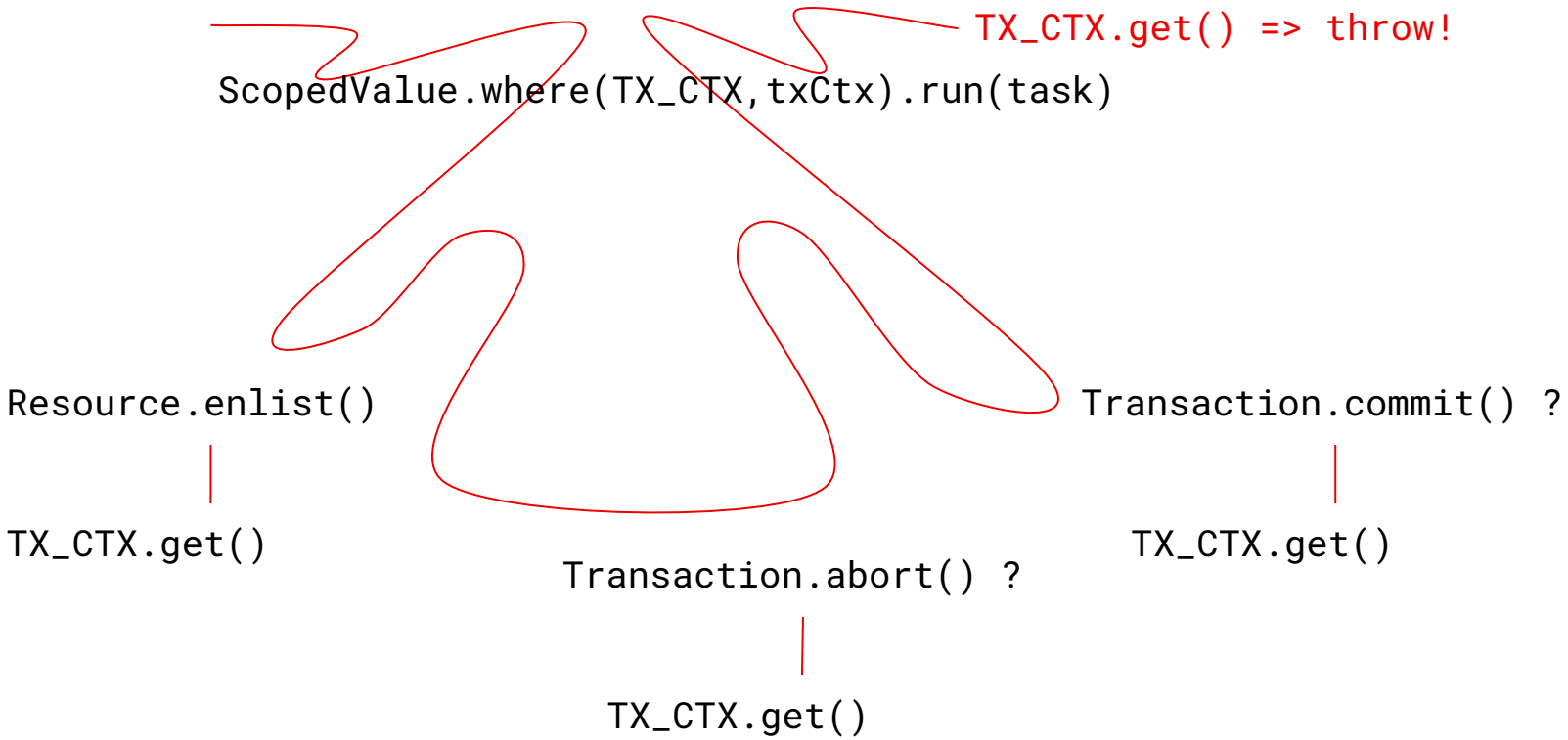

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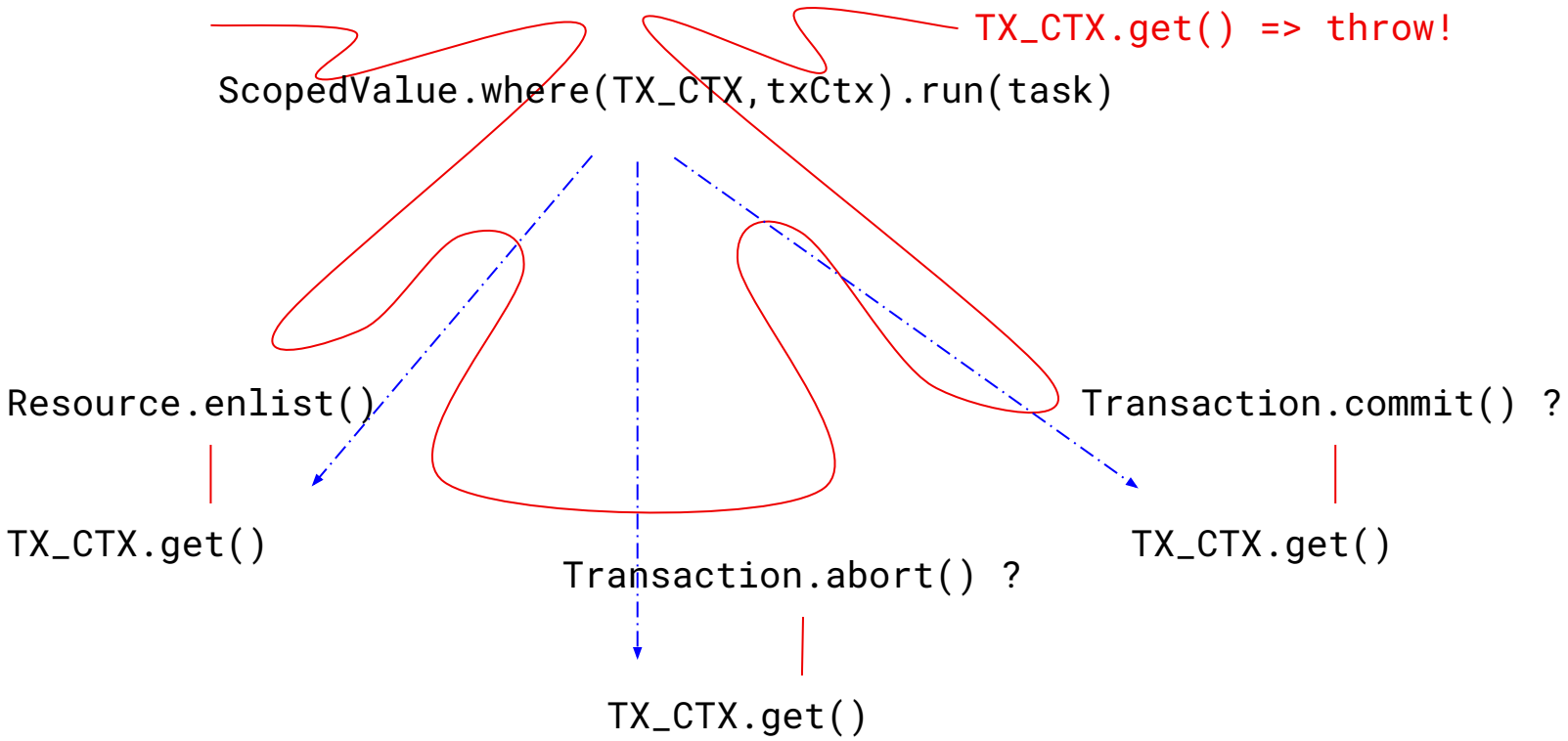

Rebinding a ScopedValue

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final staticScopedValue<TransactionContext> TX_CTX = . . .;
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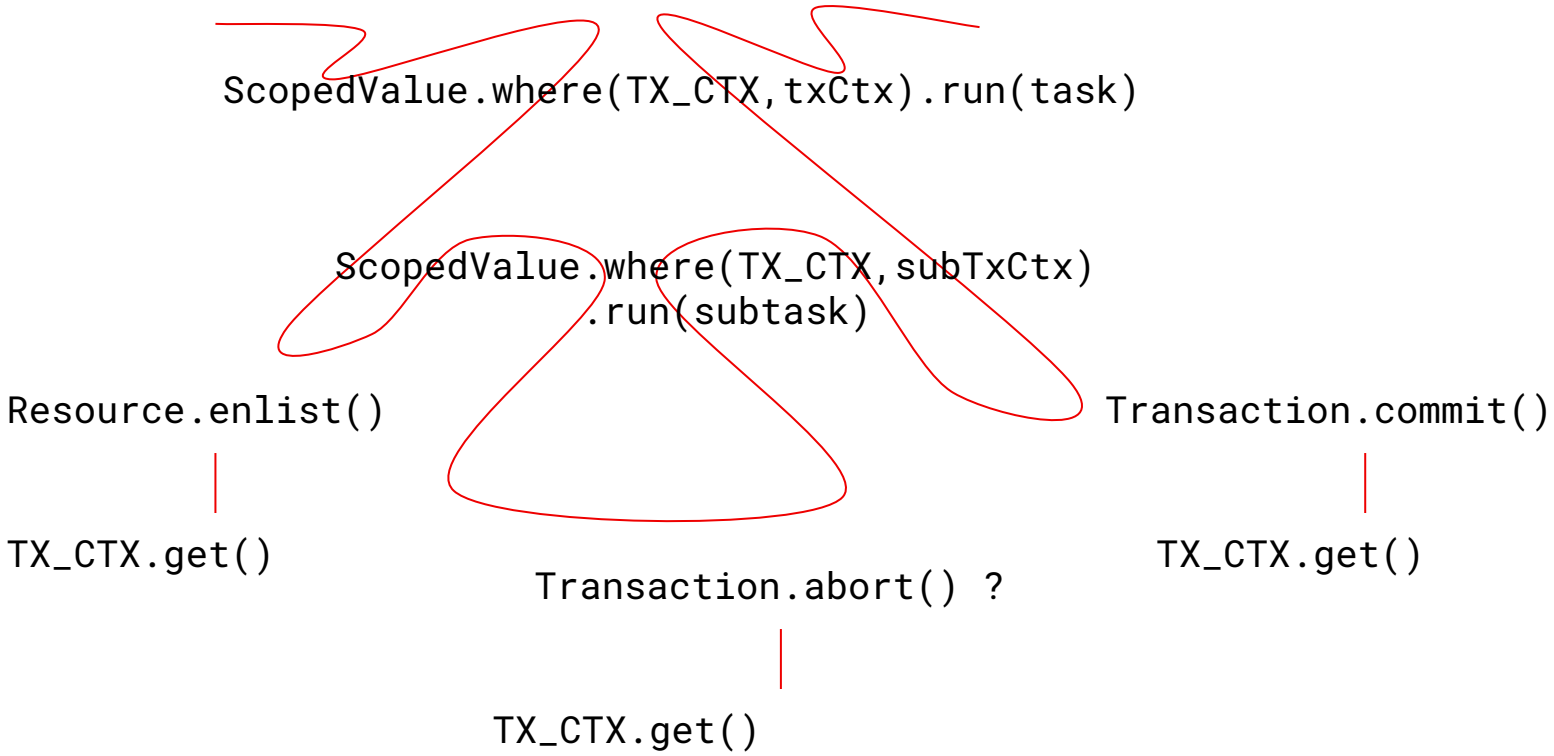

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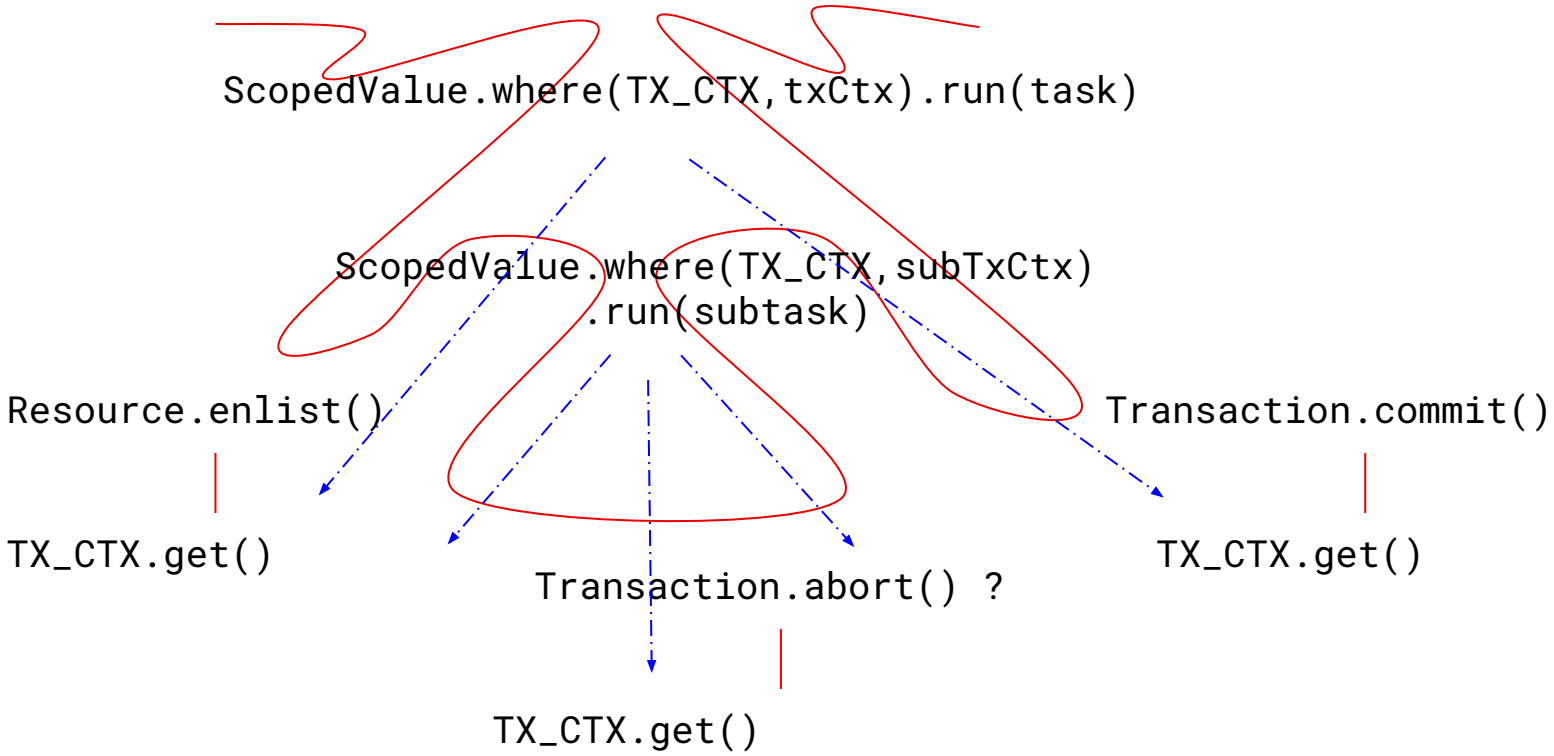

Rebinding a ScopedValue (2)

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final staticScopedValue<GraphicsContext> GR_CTX = . . .;
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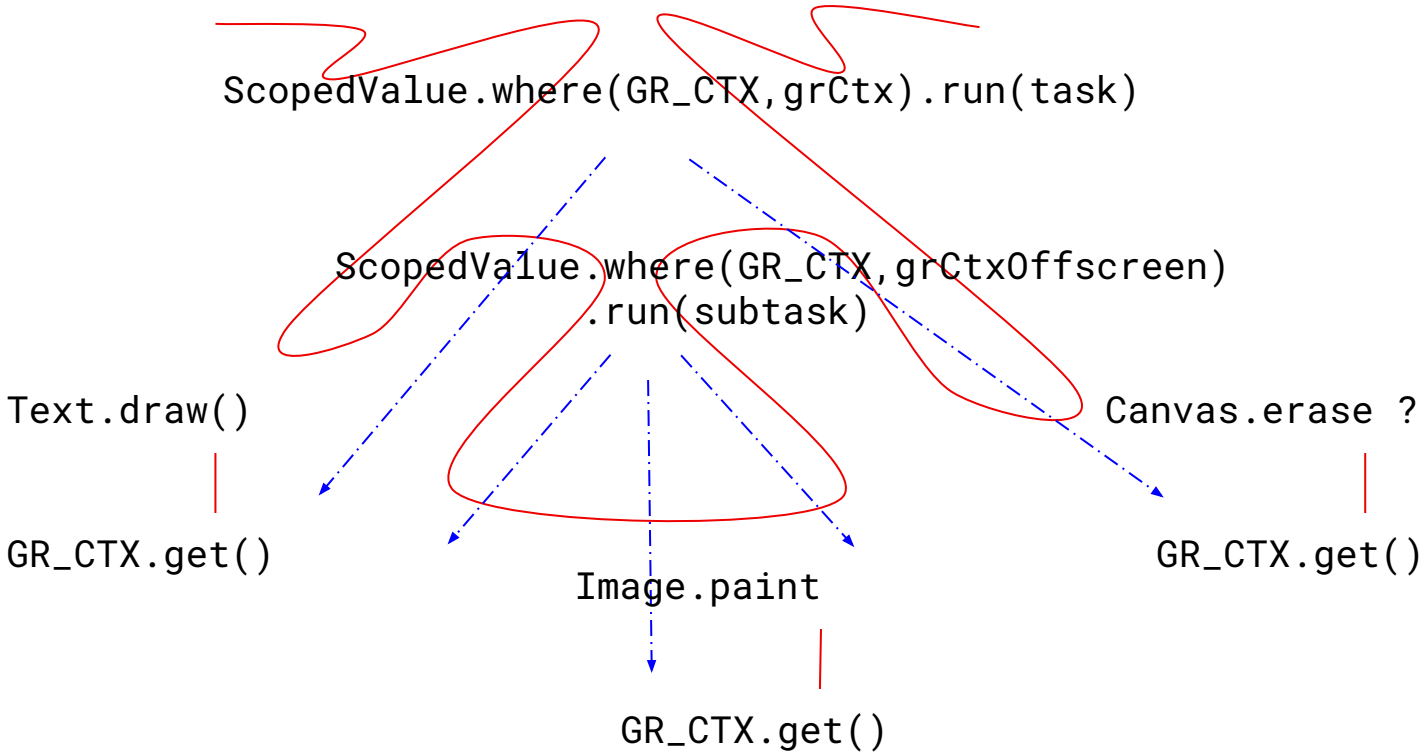

Rebinding a `ScopedValue` (3)

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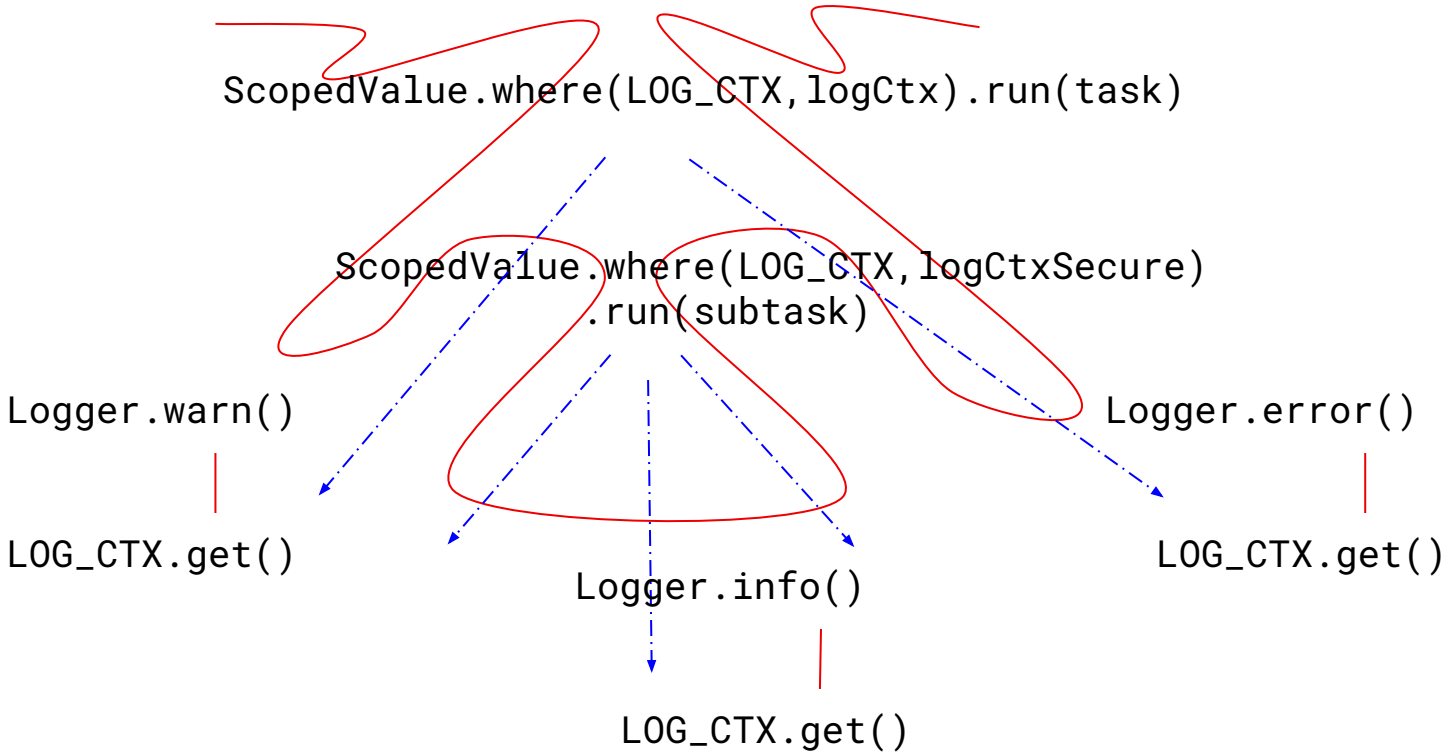

`ScopedValue` use with Structured Concurrency

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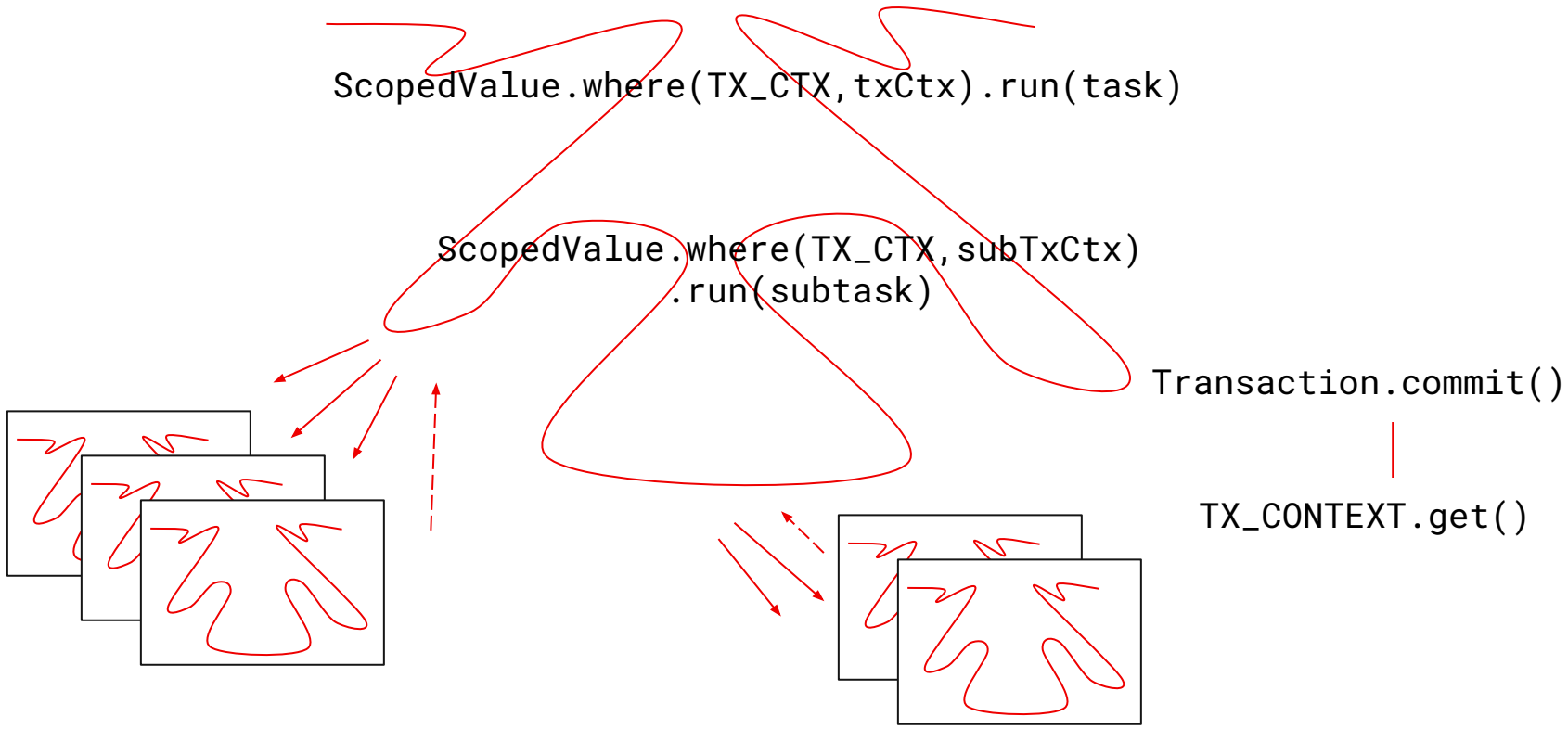

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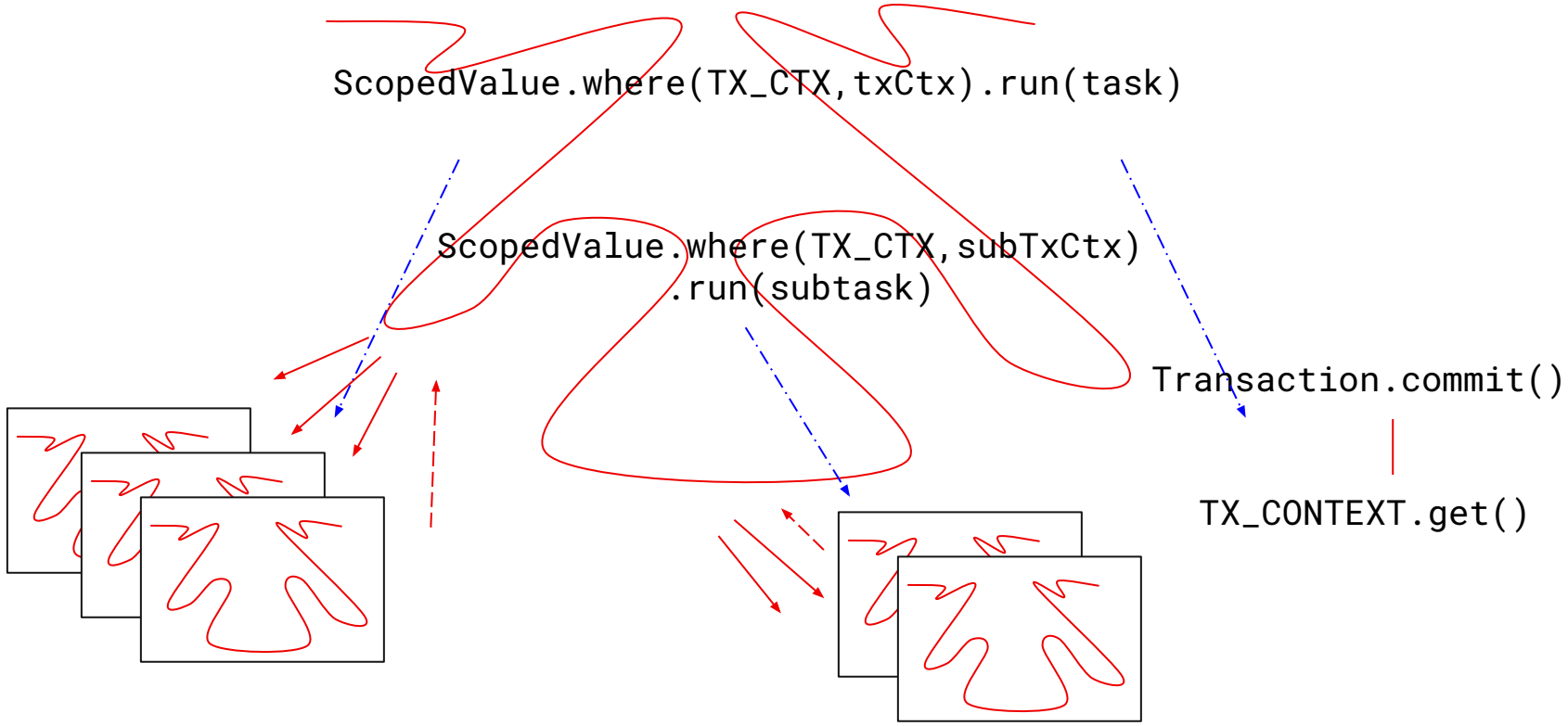

Key Differences between ScopedValues and ThreadLocals

- Scoped values have a `get()` method, but no `set()`.
- Data can only flow from a caller to its (transitive) callees
- Once the lambda which bound a scoped value exits, the binding disappears
- This is a *strong guarantee*: it is enforced by the JVM, even under extreme conditions such as stack overflow and out-of-memory

Scoped values: the wider picture

- It’s useful to think of scoped values as invisible, *effectively final*, parameters that are passed through every method invocation
- These parameters will be accessible within the *dynamic scope* of a scoped value's *binding operation*
- The dynamic scope is the set of methods invoked within the scope of the binding operation, and any methods invoked transitively by them
- The dynamic scope effectively extends across structured concurrency thread boundaries
- Access can be restricted using module/package/class access restrictions just as with Thread Locals.

Scoped values: the full API

- We tried many alternatives over a period of time, refining the API further and further, until what we have now is almost the simplest version imaginable

Scoped values: the API

All Methods | Static Methods | Instance Methods | Concrete Methods

Modifier and Type	Method	Description
`T`	`get()`	Returns the value of the scoped value if bound in the current thread.
`boolean`	`isBound()`	Returns `true` if this scoped value is bound in the current thread.
`static <T> ScopedValue`[PREVIEW]`<T>`	`newInstance()`	Creates a scoped value that is initially unbound for all threads.
`T`	`orElse(T other)`	Returns the value of this scoped value if bound in the current thread, otherwise returns `other`.
`<X extends Throwable> T`	`orElseThrow(Supplier<? extends X> exceptionSupplier)`	Returns the value of this scoped value if bound in the current thread, otherwise throws an exception produced by the exception supplying function.
`static <T> ScopedValue.Carrier`[PREVIEW]	`where(ScopedValue`[PREVIEW]`<T> key, T value)`	Creates a new `Carrier` with a single mapping of a `ScopedValue` *key* to a value.

Scoped values and Structured Concurrency

- Alan has talked about Structured Concurrency, but the key point is that scoped values in the parent thread are automatically inherited by child threads created with `StructuredTaskScope`.
- Because there is no `ScopedValue.set()` method, child threads can share data from the parent without the risk of one thread side-affecting another
- But if you really do want to share mutable state between child threads, you can still do that by using, for example, a `Reference` type

Scoped values and Structured Concurrency

- Structured Concurrency ensures that if a task splits up into concurrent subtasks then they all return to the same place, namely the task's code block. In effect, subtasks have a *bounded lifetime*.
- Scoped values ensure that once the lambda which bound a scoped value exits, the binding disappears. In effect, scoped values have a *bounded lifetime*.
- This is the essential synergy: we know that once a `StructuredTaskScope` exits, all of its child threads have terminated. It's safe to close any resources, such as files, that were shared via a Scoped Value.
- So, the combination of Scoped Values and Structured Concurrency provides a foundation for clear, safe, reliable per-thread resource management.

Addendum: Scoped values efficiency

- This talk is really about the API, not the implementation, but the API design makes efficient implementation possible
- Scoped value bindings are immutable, so are shared without any copying
- Fast access to scoped values is possible because of a small thread-local cache. This makes repeated accesses to a scoped value almost as fast as a local variable
- This cache is created for each thread as required, so threads which don't access scoped values pay no cost

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