GADTs Meet Their Match:

Pattern-Matching Warnings That Account for GADTs, Guards, and Laziness

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Pattern Syntax

$$
\begin{array}{rlcl}
K \in & \text{Con} & & \\
x, y, a, b \in & \text{Var} & & \\
\tau, \sigma \in & \text{Type} & & \\
e \in & \text{Expr} & ::= & x : \tau \\
 & & \mid & K\ \overline{a}\ \overline{\gamma}\ \overline{e : \tau} \\
 & & \mid & \ldots \\
\gamma \in & \text{TyCt} & ::= & \tau_1 \sim \tau_2 \mid \ldots \\
g \in & \text{Grd} & ::= & \text{let } x : \tau = e; \\
 & & \mid & K\ \overline{a}\ \overline{\gamma}\ \overline{y : \tau} \leftarrow x; \\
 & & \mid & !x;
\end{array}
$$

Oracle Syntax

$$
\begin{array}{lcll}
\Gamma & ::= & \varnothing \mid \Gamma, x : \tau \mid \Gamma, a & \text{Context} \\
\Delta & ::= & \times \mid \checkmark \mid \Delta, \delta \mid \Delta_1 \vee \Delta_2 & \text{Delta} \\
\delta & ::= & \gamma \mid x_1 \approx x_2 \mid K\ \overline{x : \tau} \leftarrow y \mid x \not\approx K \mid x \approx \bot \mid x \not\approx \bot \mid x \approx e & \text{Constraints}
\end{array}
$$

1 PROBLEMS WITH CTT

`ctt` i s rather simple now, but it assumes that the incoming Δ is basically unconstrained (e.g. $\checkmark$). But that certainly is not true for any clause after the first! Intuitively, we replace all leafs in the incoming Δ (which are $\checkmark$, since we can immediately prune $\times$). Example:

```
data T = A | B | C
f A A = ()
f B B = ()
f C C = ()
```

We start with $\{(x, y)$ `\nodelta \}$ for the uncovered set. After the first clause, we have $\`
$A, \checkmark) \vee (A \leftarrow x, y \not\approx A, \checkmark)\}$ for the uncovered set flowing into the second clause.

The result of `ctt` a pplied to the second clause is $(x \not\approx B, \checkmark) \vee (B \leftarrow x, y \not\approx B, \checkmark)$. But that doesn't consider the incoming uncovered set! For that, we have to substitute every $\checkmark$ in the incoming uncovered set by the constraint tree we just computed.

In tree form. Incoming Δ:

```
        \/
      /    \
  x/=A    A<-x
    |       |
    ✓     y/=A
            |
            ✓
```

Δ from `ctt` o n the second clause:

```
        \/
      /    \
  x/=B    B<-x
    |       |
    ✓     y/=B
            |
            ✓
```

Substituted into the first Δ:

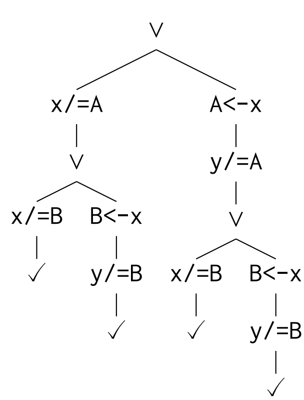
Clause tree

$$
\begin{array}{rcl}
\mathcal{T}[r] & ::= & \texttt{Rhs} \\
 & \mid & \texttt{Many}\ \overline{r} \\
 & & \\
t_G \in \text{Gdt} & ::= & \mathcal{T}[t_G] \\
 & \mid & \texttt{Guard}\ g\ t_G \\
 & & \\
t_C \in \text{Ctt} & ::= & \mathcal{T}[t_C] \\
 & \mid & \lightning?\ \delta\ t_C \\
 & \mid & \texttt{FallThroughIf}\ \delta\ t_C \\
 & \mid & \texttt{Refine}\ \delta\ t_C \\
 & & \\
t_A \in \text{Ant} & ::= & \mathcal{T}[t_A] \\
 & \mid & \texttt{Diverges}\ t_A \\
 & \mid & \texttt{Inaccessible}\ t_A
\end{array}
$$

Compiling constraint trees

$$\boxed{\text{cct Gdt} = \text{Ctt}}$$

$$
\begin{array}{lcl}
\texttt{cct Rhs} & = & \texttt{Rhs} \\
\texttt{cct Many}\ \overline{t_G} & = & \texttt{Many}\ \overline{\texttt{cct}\ t_G} \\
\texttt{cct Guard}\ (\text{let}\ x = e;)\ t_G & = & \texttt{cctg}\ g\ (\texttt{cct}\ t_G) \\
\texttt{cctg}\ (\text{let}\ x = e;) & = & \texttt{Refine}\ (x \approx e) \\
\texttt{cctg}\ (!x;) & = & \lightning?\ (x \approx \bot)\ \circ \texttt{Refine}\ (x \not\approx \bot) \\
\texttt{cctg Guard}\ (!x;) & = & \lightning?\ (x \approx \bot)\ \circ \texttt{Refine}\ (x \not\approx \bot) \\
\texttt{cct Guard}\ (K\ \overline{a}\ \overline{\gamma}\ \overline{y : \tau} \leftarrow x;)\ t_G & = & \lightning?\ (x \approx \bot)\ (\lightning?\ (x \approx \bot)\ (\texttt{Refine}\ (x \approx K\ \overline{x : \tau} \leftarrow y)\ \texttt{ctt}\ t_G\ ))
\end{array}
$$



Note that we now have 4 ✓s. So this substitution step reintroduces the exponential blowup.

That alone wouldn't be a problem: Currently, we also would have 4 Δs in flight for this program. But if we execute on the plan here to separately translate Grd into Con trees for each clause, and then only *afterwards* (after the substitution step, that is) check for inhabitants (which is conceptually very beautiful), we run into efficiency problems in the implementation, because we have no way to share the work involved with checking the *very similar* branches we just substituted.

It's a lot like choosing the most efficient evaluation strategy, really! Doing the substitution before we digest the tree into a more computably tractable form (like in the current implementation where we cache residual COMPLETE sets) is a lot like call-by-name and we get asymptotically behavior in supposedly trivial cases. The current implementation is more like call-by-value in that regard.

Example, inspired by the test case `ManyAlternatives`:

```
data T = T1 | ... | T1000
f T1 = ()
...
f T1000 = ()
```

The constraint tree of the *covered* set of the 1000th clause will look like this:

```
T1000<-x
   |
  ...
   |
x/=T999
   |
 x/=T1
   |
   ✓
```

The other covered sets are similar. In order to determine whether a clause is redundant, we have to check each of these covered sets for inhabitants! But with COMPLETE sets, we have to constantly check whether the negative constraints form a COMPLETE set. That's very inefficient! And it's the reason we currently have the `vi_cache` field in `VarInfo`: For gradually deleting candidates from the residual COMPLETE sets when we move from clause to clause instead of always beginning from scratch (the full COMPLETE set) at each clause and thinning it out with linearly many negative constraints.

So we definitely want the same kind of caching in our new constraint tree representation. Now here's the problem: I don't currently see how! Intuitively, sharing of work is only possible along the shared path from the root of the final constraint tree we check for inhabitants to one of its leafs. Note how that's not possible in the tree above, because each tree will have a different root, so no sharing on any such paths! If we had the following constraint trees instead:

```
 x/=T1
   |
  ...
   |
x/=T999
   |
T1000<-x
   |
   ✓
```

I.e. with the order of inner nodes reversed, we could share residual COMPLETE sets along the shared path prefix. E.g. the the clause for `T500` could re-use the residual COMPLETE sets from `T499`, like it's currently the case.

To achieve this, we have to roll back to the old constraint tree generation scheme, where we pass the incoming Δ to `ctt` .

Test if Oracle state Delta is unsatisfiable

$$\boxed{\nvdash_{\textsc{Sat}} \Gamma \vdash \Delta}$$

$$\frac{\nvdash_{\textsc{Sat}} \Gamma \vdash fvs\Gamma \ \triangleright \ \Delta}{\nvdash_{\textsc{Sat}} \Gamma \vdash \Delta}$$

Test a list of SAT roots for inhabitants

$$\boxed{\nvdash_{\textsc{Sat}} \Gamma \vdash \overline{x} \ \triangleright \ \Delta}$$

$$\frac{\nvdash_{\textsc{Sat}} \Gamma \vdash x_i \ \triangleright \ \Delta}{\nvdash_{\textsc{Sat}} \Gamma \vdash \overline{x} \ \triangleright \ \Delta}$$

Test a single SAT root for inhabitants

$$\boxed{\nvdash_{\textsc{Sat}} \Gamma \vdash x \ \triangleright \ \Delta}$$

$$\frac{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx \bot \qquad \{\overline{K}\} \text{ COMPLETE set} \qquad \overline{\forall \overline{y : \tau}. \nvdash_{\textsc{Sat}} \Gamma, \overline{y : \tau} \vdash \ \oplus \Delta x \approx K \ \overline{y}}}{\nvdash_{\textsc{Sat}} \Gamma \vdash x \ \triangleright \ \Delta}$$

Add a single equality to Δ

$$\boxed{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta\delta}$$

Term stuff: Bottom, negative info, positive info + generativity, positive info + univalence

$$\frac{x \not\approx sth \in \Delta}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx \bot} \qquad \frac{x \approx K \ \overline{y} \in \Delta}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx \bot}$$

$$\frac{x \not\approx K \in \Delta}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx K \ \overline{y}} \qquad \frac{x \approx K_i \ \overline{y} \in \Delta \quad i \neq j \quad K_i \text{ and } K_j \text{ generative}}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx K_j \ \overline{z}}$$

$$\frac{x \approx K \ \overline{\tau} \ \overline{y} \in \Delta \quad \nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta \tau_i \sim \sigma_i}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx K \ \overline{\sigma} \ \overline{z}} \qquad \frac{x \approx K \ \overline{\tau} \ \overline{y} \in \Delta \quad \nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta y_i \approx z_i}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx K \ \overline{\sigma} \ \overline{z}}$$

Type stuff: Hand over to unspecified type oracle

$$\frac{\tau_1 \text{ and } \tau_2 \text{ incompatible to Givens in } \Delta \text{ according to type oracle}}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta \tau_1 \sim \tau_2}$$

Mixed: Instantiate K and see if that leads to a contradiction TODO: Proper instantiation

$$\frac{\overline{\nvdash_{\textsc{Sat}} \Gamma \vdash y \ \triangleright \ \Delta \cup y \not\approx \bot}}{\nvdash_{\textsc{Sat}} \Gamma \vdash \ \oplus \Delta x \approx K \ \overline{y}}$$

TODO LIST

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