# Bidirectional Programming Languages

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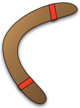
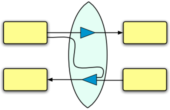
April 2009






redact
exchange
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integrate
query
analyze
update
mashup
transform
clean
curate
reconcile
data
modify
hide
maintain
synchronize
extract
summarize
evolve

We *can* write complicated data transformations in C...


or Java...


or C++...

...or a tool specifically designed for the task!

# Domain-specific languages

- Clean semantics
- Natural syntax
- Better tools


data
update
query
mashup
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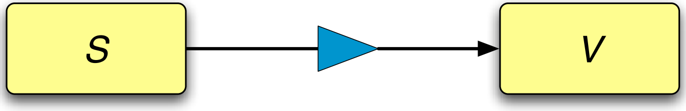
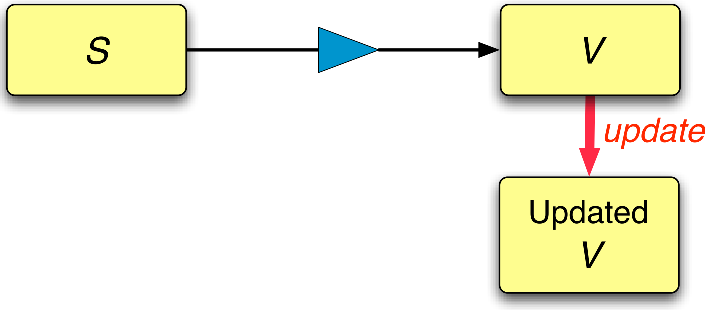
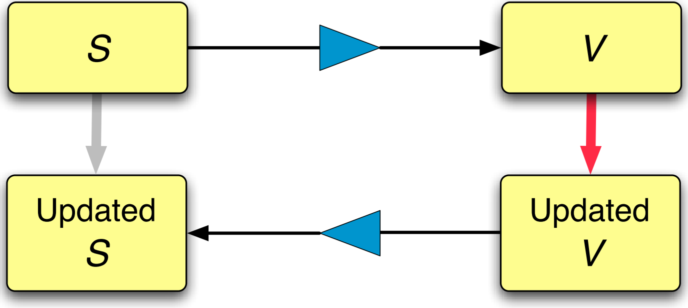

S
V

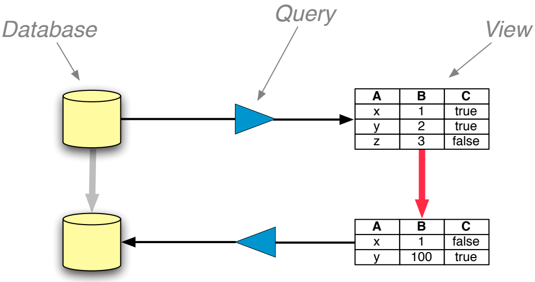


S
V
update
Updated
V


S
V
Updated S
Updated V

# The View Update Problem

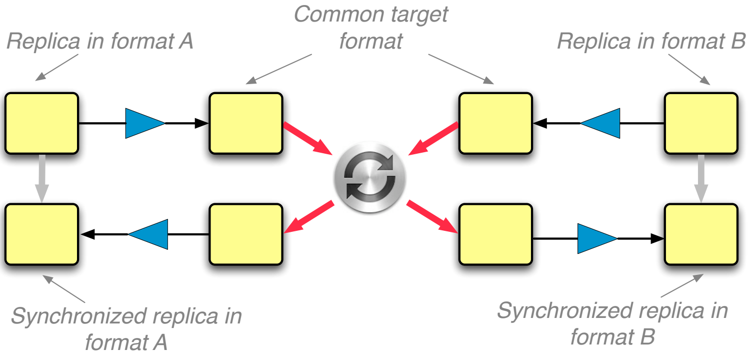
In databases, this is known as the view update problem.




[Bancilhon, Spryatos '81]

# The View Update Problem In Practice

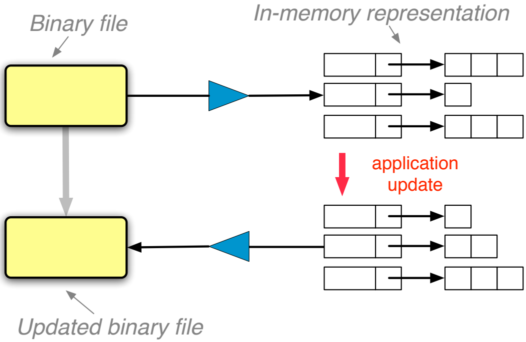
It also arises in data converters and synchronizers...




[Foster, Greenwald, Pierce, Schmitt JCSS '07]— Harmony

# The View Update Problem In Practice

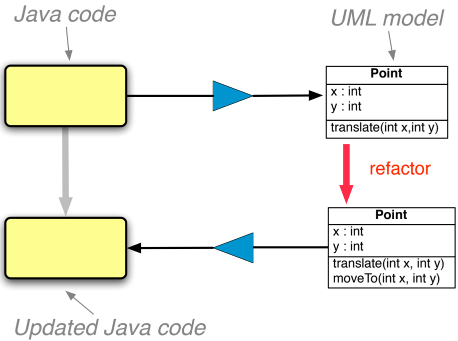
...in picklers and unpicklers...




[Fisher, Gruber '05]— PADS

# The View Update Problem In Practice

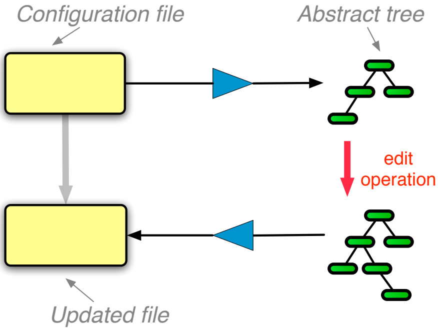
...in model-driven software development...




[Stevens '07]— bidirectional model transformations

# The View Update Problem In Practice

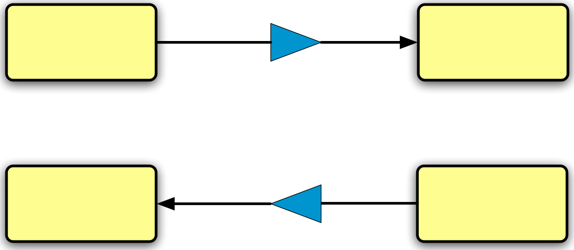
...in tools for managing operating system configurations...




[Lutterkort '08]— Augeas

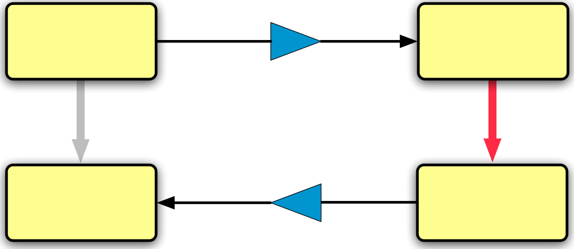
# Problem

How do we write these bidirectional transformations?



# Problem: Why is it hard?

We want updates to the view to be translated "exactly"...



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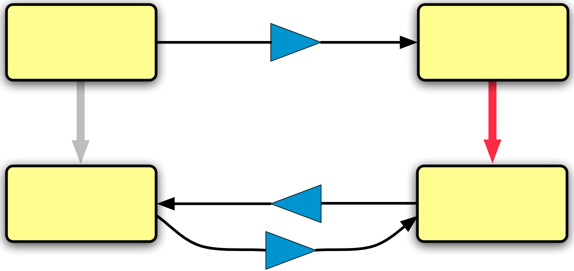
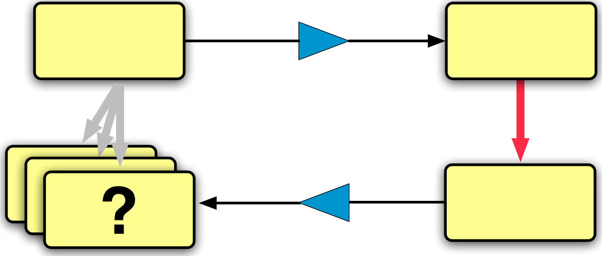


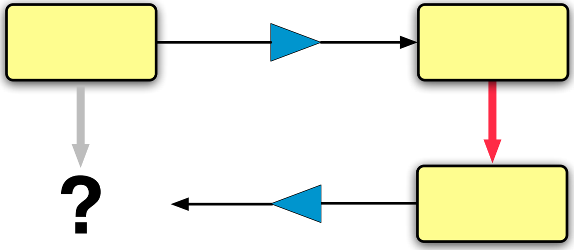
# Problem: Why is it hard?

...but some updates have *many* corresponding source updates...

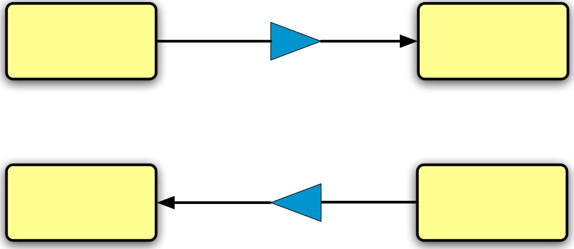


# Problem: Why is it hard?

...while others have *none*!



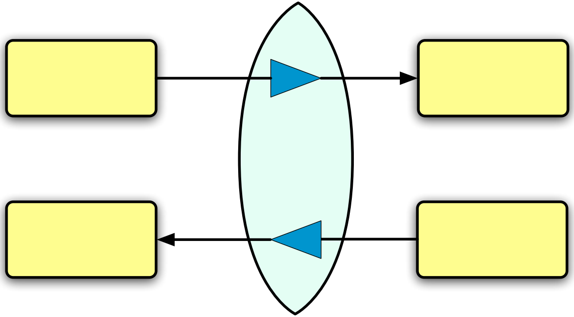
# Possible Approaches



**Bad:** write the two transformations as separate functions.

- tedious to program
- difficult to get right
- a nightmare to maintain

# Possible Approaches



**Good:** derive both transformations from the same program.

- Clean semantics: behavioral laws guide language design
- Natural syntax: parsimonious and compositional
- Better tools: type system guarantees well-behavedness

# This talk: Goal

"Bidirectional programming languages are an effective and elegant means of describing updatable views"

# This talk: Outline

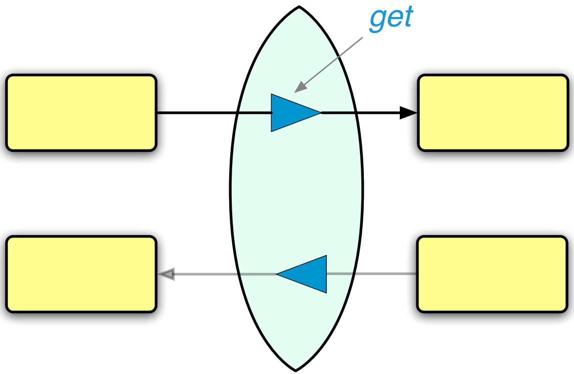
1. Lenses
   - Design goals
   - Semantics
2. String Lenses
   - Core operators
   - Type system
3. Boomerang
   - Ordered data
   - Ignorable data
   - Implementation & Applications
4. Ongoing Work
   - Updatable Security Views
5. Future Directions
   - Data provenance
   - Model transformations

[Foster, Greenwald, Moore, Pierce, Schmitt TOPLAS '07]

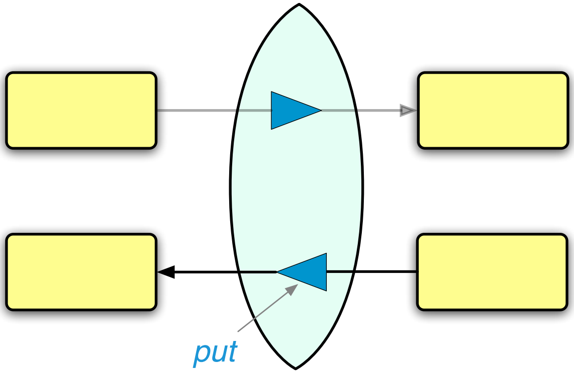
# Lenses

''‘Never look back unless
you are planning to go that way"
—H D Thoreau

# Terminology



# Terminology



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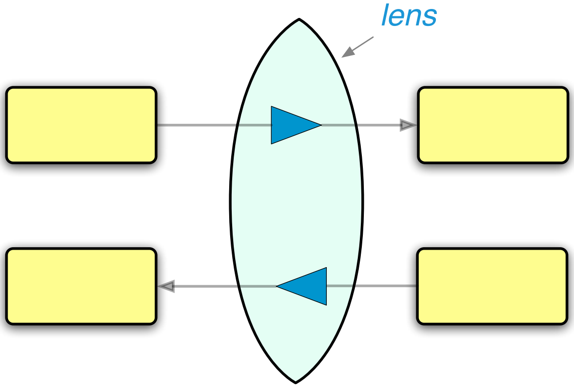


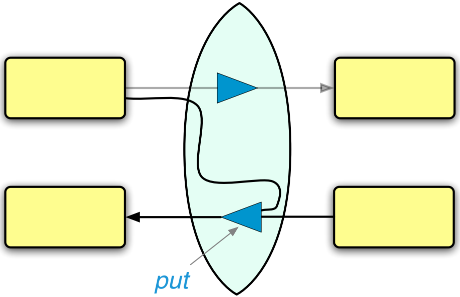
# Bidirectional vs. Bijective

Goal #1: lenses should be capable of hiding source data.

# Bidirectional vs. Bijective

Goal #1: lenses should be capable of hiding source data.

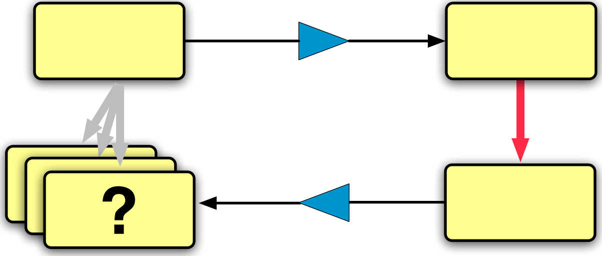
- In general, **get** may be non-injective
- and so **put** needs to take the original source as an argument




(Of course, the purely bijective case is also very interesting.)

# Choice of Put Function

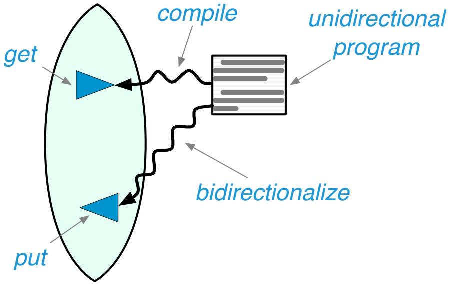
Recall that for some view updates there are *many* corresponding source updates.



# Choice of Put Function

Goal #2: programmers should be able to choose a **put** function that embodies an appropriate policy for propagating updates back to sources.

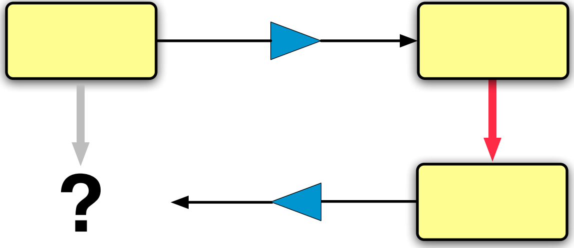
“Bidirectionalization” appears attractive...




...but does not provide a way to make this choice.

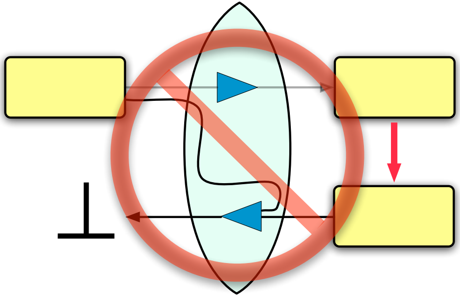
# Totality

Recall that some view updates do not have *any* corresponding source updates.



# Totality

Goal #3: the **put** function should be a total function, capable of doing *something* reasonable with every view and source.




Totality ensures that the view is a robust abstraction, but forces us to use an extremely precise type system.

# Well-Behaved Lenses

A lens $l$ mapping between a set $S$ of sources and $V$ of view is a pair of total functions

$$\begin{aligned} l.\mathbf{get} &\in S \rightarrow V \\ l.\mathbf{put} &\in V \rightarrow S \rightarrow S \end{aligned}$$

obeying "round-tripping" laws

$$l.\mathbf{get}\ (l.\mathbf{put}\ v\ s) = v \qquad (\textsc{PutGet})$$

$$l.\mathbf{put}\ (l.\mathbf{get}\ s)\ s = s \qquad (\textsc{GetPut})$$

for every $s \in S$ and $v \in V$.

# Related Frameworks

Databases: *many* related ideas

- [Dayal, Bernstein '82] "exact translation"
- [Bancilhon, Spryatos '81] "constant complement"
- [Gottlob, Paolini, Zicari '88] "dynamic views"

User Interfaces: [Meertens '98] "constraint maintainers"

See [Foster *et. al* TOPLAS '07] for details...

# Related Languages

Harmony Group @ Penn

- [Foster *et al.* TOPLAS '07] — trees
- [Bohannon, Pierce, Vaughan PODS '06] — relations
- [Foster *et al.* JCSS '07] — data synchronizer

Bijective languages

- [PADS Project @ AT&T] — picklers and unpicklers
- [Hosoya, Kawanaka '06] — biXid
- [Braband, Møller, Schwartzbach '05] — XSugar

Bidirectional languages

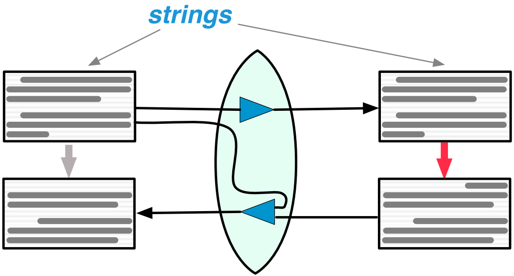
- [PSD @ Tokyo] — "bidirectionalization", structure editors
- [Gibbons, Wang @ Oxford] — Wadler's views
- [Voïgtlaender '09] — bidirectionalization "for free"
- [Stevens '07] — lenses for model transformations

[Bohannon, Foster, Pierce, Pilkiewicz, Schmitt POPL '08]

# String Lenses

"The art of progress is
to preserve order amid change
and to preserve change amid order."
—A N Whitehead

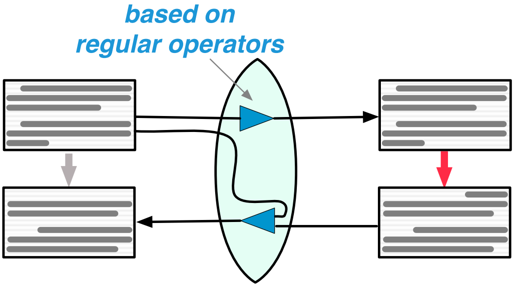
# Data Model




Why strings?

1. Simple setting $\longrightarrow$ exposes fundamental issues
2. There's a lot of string data in the world
3. Programmers are already comfortable with regular operators (union, concatenation, and Kleene star)

# Computation Model

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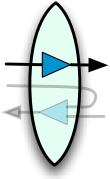
# Example: Redacting Lens (Get)

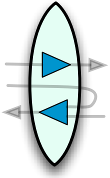
```
*08:30 Coffee with Sara (Starbucks)
 12:15 PLClu (Seminar room)
*15:00 Workout (Gym)
```



```
08:30 BUSY
12:15 PLClu
15:00 BUSY
```

# Example: Redacting Lens (Update)

```
*08:30 Coffee with Sara (Starbucks)
 12:15 PLClu (Seminar room)
*15:00 Workout (Gym)
```



```
08:30 BUSY
12:15 PLClu
15:00 BUSY
```

```
08:30 BUSY
12:15 PLClub
15:00 BUSY
16:00 Meeting
```

# Example: Redacting Lens (Put)

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```

```
08:30 BUSY
12:15 PLClu
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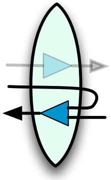

```
*08:30 Coffee with Sara (Starbucks)
 12:15 PLClub (Seminar room)
*15:00 Workout (Gym)
 16:00 Meeting (Unknown)
```

```
08:30 BUSY
12:15 PLClub
15:00 BUSY
16:00 Meeting
```

# Example: Redacting Lens (Definition)

```
(* regular expressions *)
let TEXT : regexp = ([^\n\\()] | "\\(" | "\\)" | "\\\\")*
let TIME : regexp = DIGIT{2} . COLON . DIGIT{2} . SPACE
let LOCATION : regexp = SPACE . LPAREN . TEXT . RPAREN

(* helper lenses *)
let public : lens =
  del SPACE .
  copy TIME .
  copy TEXT .
  default (del LOCATION) " (Unknown)"

let private : lens =
  del ASTERISK .
  copy TIME .
  default (TEXT . LOCATION <-> "BUSY") "Unknown (Unknown)"

let event : lens =
  (public | private) .
  copy NL

(* main lens *)
let redact : lens = event*
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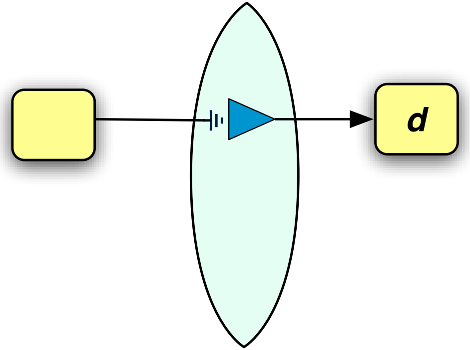
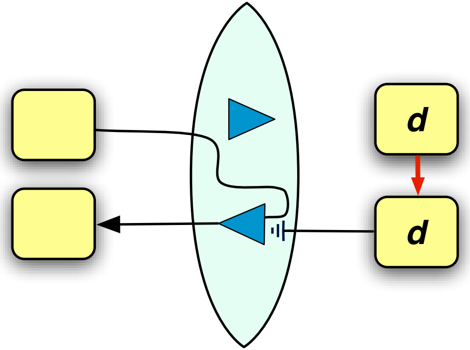
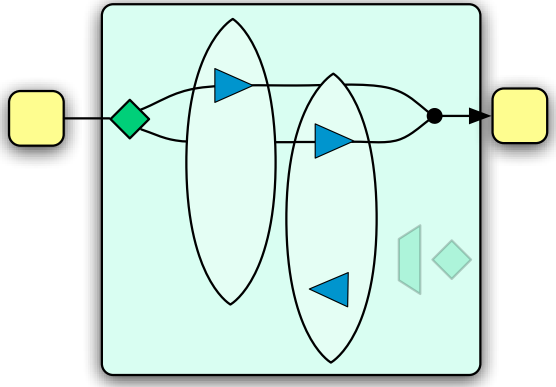
## $E \leftrightarrow d$ (Get)

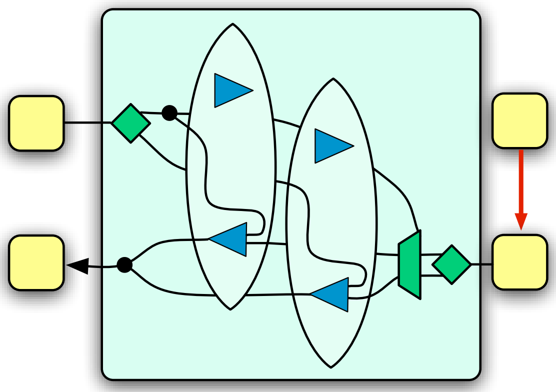


# $E \leftrightarrow d$ (Put)



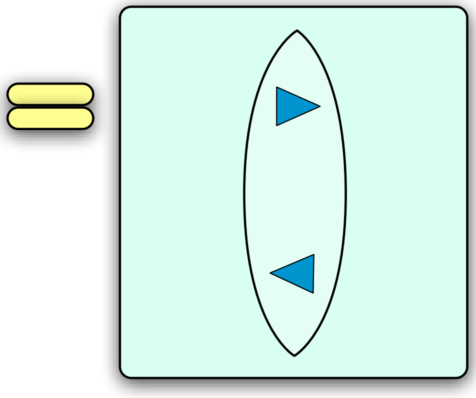


Type system ensures that choice is deterministic.

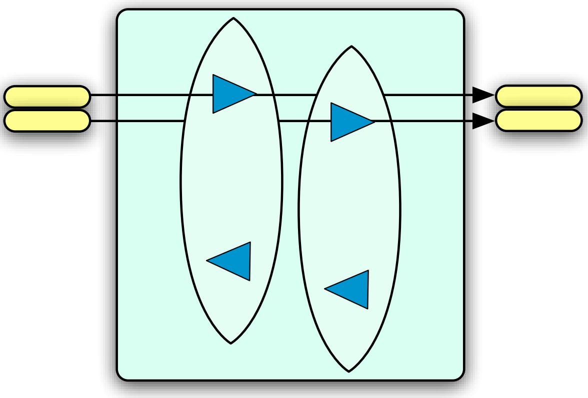


Type system ensures that choice is deterministic.

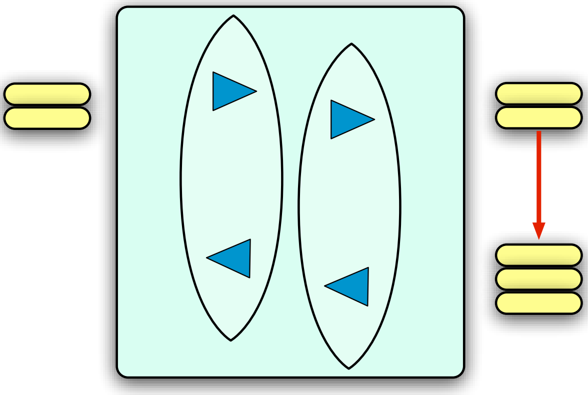
# l*            (Get)



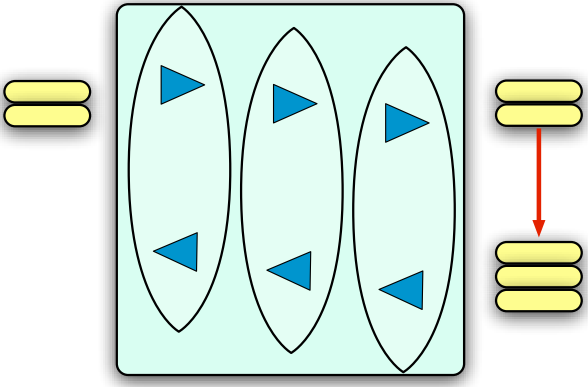
# l* (Get)



# I* (Put)



# /*                (Put)



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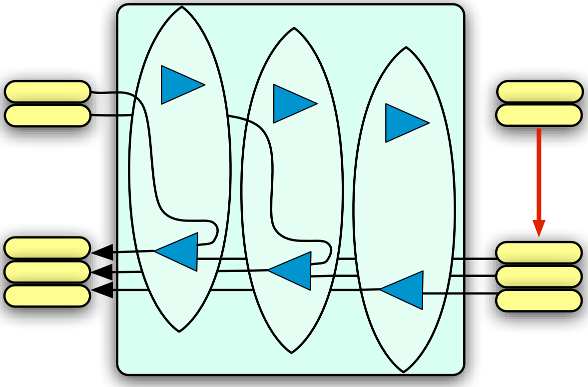

Type system ensures that strings are split the same way.

# String Lens Type System

Based on regular expression types...

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$$\frac{}{\mathit{copy}\ E \in [\![E]\!] \Longleftrightarrow [\![E]\!]} \qquad \frac{}{E \leftrightarrow d \in [\![E]\!] \Longleftrightarrow \{d\}}$$

$$\frac{l \in S \Longleftrightarrow V \qquad d \in [\![S]\!]}{\mathit{default}\ l\ d \in S \Longleftrightarrow V} \qquad \frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cdot^! S_2 \\ l_2 \in S_2 \Longleftrightarrow V_2 & V_1 \cdot^! V_2 \end{array}}{(l_1 \cdot l_2) \in S_1 \cdot S_2 \Longleftrightarrow V_1 \cdot V_2}$$

$$\frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cap S_2 = \emptyset \\ l_2 \in S_2 \Longleftrightarrow V_2 & \end{array}}{(l_1 \mid l_2) \in S_1 \cup S_2 \Longleftrightarrow V_1 \cup V_2} \qquad \frac{l \in S \Longleftrightarrow V \qquad S^{!*} \qquad V^{!*}}{l^* \in S^* \Longleftrightarrow V^*}$$

$S_1 \cdot^! S_2$ (or $S^{!*}$) means that the concatenation (or iteration) is unambiguous.

# String Lens Type System

Based on regular expression types...

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$$\frac{}{E \leftrightarrow d \in [\![E]\!] \Longleftrightarrow \{d\}}$$

$$\frac{l \in S \Longleftrightarrow V \qquad d \in [\![S]\!]}{\textit{default } l \ d \in S \Longleftrightarrow V}$$

$$\frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cdot^! S_2 \\ l_2 \in S_2 \Longleftrightarrow V_2 & V_1 \cdot^! V_2 \end{array}}{(l_1 \cdot l_2) \in S_1 \cdot S_2 \Longleftrightarrow V_1 \cdot V_2}$$

$$\frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cap S_2 = \emptyset \\ l_2 \in S_2 \Longleftrightarrow V_2 & \end{array}}{(l_1 \mid l_2) \in S_1 \cup S_2 \Longleftrightarrow V_1 \cup V_2}$$

$$\frac{l \in S \Longleftrightarrow V \qquad S^{!*} \qquad V^{!*}}{l* \in S* \Longleftrightarrow V*}$$

$S_1 \cdot^! S_2$ (or $S^{!*}$) means that the concatenation (or iteration) is unambiguous.

# String Lens Type System

Based on regular expression types...

$$\frac{}{\textit{copy}\ E \in [\![E]\!] \Longleftrightarrow [\![E]\!]} \qquad \frac{}{E \leftrightarrow d \in [\![E]\!] \Longleftrightarrow \{d\}}$$

$$\frac{l \in S \Longleftrightarrow V \qquad d \in [\![S]\!]}{\textit{default}\ l\ d \in S \Longleftrightarrow V} \qquad \frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cdot^! S_2 \\ l_2 \in S_2 \Longleftrightarrow V_2 & V_1 \cdot^! V_2 \end{array}}{(l_1 \cdot l_2) \in S_1 \cdot S_2 \Longleftrightarrow V_1 \cdot V_2}$$

$$\frac{\begin{array}{ll} l_1 \in S_1 \Longleftrightarrow V_1 & S_1 \cap S_2 = \emptyset \\ l_2 \in S_2 \Longleftrightarrow V_2 & \end{array}}{(l_1 \mid l_2) \in S_1 \cup S_2 \Longleftrightarrow V_1 \cup V_2} \qquad \frac{l \in S \Longleftrightarrow V \qquad S^{!*} \qquad V^{!*}}{l^* \in S^* \Longleftrightarrow V^*}$$

$S_1 \cdot^! S_2$ (or $S^{!*}$) means that the concatenation (or iteration) is unambiguous.

**Theorem**

If $l \in S \Longleftrightarrow V$ then $l$ is a well-behaved lens.

# Comparison: Separate Functions

```
module B = Buffer
module R = Str
module L = List
module U = Unix
let rx = R.regexp
let sch = R.search_forward

(* helpers *)
let error s =
  print_string s;
  exit 1

let exec s =
  let buf = B.create 17 in
  let p = U.open_process_in s in
  (try
    while true do B.add_char buf (input_char p) done
  with End_of_file -> ());
  ignore (U.close_process_in p);
  B.contents buf

(* regexps *)
let begin_event = rx "BEGIN:VEVENT"
let text = "[^\n]*"
let esctext = "([^\n\\()]\\|\\\\\\|\\(\\|\\))*"
let date = "[0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9]T[0-9][0-9][0-9][0-9][0-9][0-9]Z"
let codes = [("\\", "\\\\"); ("(","\\("); (")","\\)")]

let today () = exec "date +%Y%m%d | tr -d '\n'"
let now () = exec "date +%H%M%S | tr -d '\n'"
let uid () = exec "cat /dev/urandom|uuencode -m -|tail +2|tr -dc 'a-zA-Z0-9'|head -c25"

(* dictionary lens helpers *)
let escape codes s =
  L.fold_right
    (fun (p,r) s -> R.global_replace (rx p) r s)
    codes
    s

let unescape codes s =
  L.fold_left
    (fun s (p,r) -> R.global_replace (rx r) p s)
    s codes

let distance s1 s2 =
  let m,n = String.length s1, String.length s2 in
  let aodd,aeven = Array.make (succ n) 0,Array.make (succ n) 0 in
    for j=0 to n do aeven.(j) <- j done;
    for i=1 to m do
      let apredi = if i mod 2 = 0 then aodd else aeven in
      let ai = if i mod 2 = 0 then aeven else aodd in
        ai.(0) <- i;
        for j = 1 to n do
          let x =
            if String.get s1 (pred i) = String.get s2 (pred j) then 0 else 1 in
          ai.(j) <-
            (min (apredi.(j) + 1) (min (ai.(j-1) + 1) (apredi.(j-1) + x)));
        done
    done;
    if m mod 2 = 0 then aeven.(n) else aodd.(n)

let rec lookup k l =
  let l' = L.map (fun (ki,ci) -> (distance ki k,ki,ci)) l in
  let rec aux acc l = match acc,l with
      None,[] -> None
      Some(_,ki,ci),[] -> Some(ki,ci)
      Some(di,ki,ci),(dj,kj,cj)::rest when dj < di -> aux (Some(dj,kj,cj)) rest
      None,(dj,kj,cj)::rest -> aux (Some(dj,kj,cj)) rest
      _,_::rest -> aux acc rest in
  aux None l'

let remove k l =
  let rec loop acc = function
      [] -> L.rev_append acc []
      h::t when k = fst h -> L.rev_append acc t
      h::t -> loop (h::acc) t in
  loop [] l

let wrap b =
  let b_len = String.length b in
  let buf,line_buf,aux_buf = B.create b_len, B.create 75, B.create 75 in
  let do_it s b =
    if B.length line_buf <> 0 then B.add_string buf s;
    B.add_buffer buf b;
    B.reset b in
  let rec loop i =
    let sum =
      let aux_len = B.length aux_buf in
      let line_len = let n = B.length line_buf in if n=0 then n else succ n in
      aux_len + line_len in
    if sum > 75 then do_it "\n" line_buf;
```

Helpers

```
    if i = b_len then (do_it " " aux_buf; do_it "\n" line_buf)
    else
      (if b.[i] = ' ' then do_it " " aux_buf
       else B.add_char aux_buf b.[i];
       loop (succ i)) in
  loop 0;
  B.contents buf

let unwrap c = R.global_replace (rx "\n") (String.make 1 ' ') c

let field tag r s =
  try
    ignore(sch (rx (tag ^ ":" ^ "\\(" ^ r ^ "\\)\n")) s 0);
    R.matched_group 1 s
  with Not_found -> error ("Couldn't find " ^ tag ^ " in " ^ s ^ "\n")

let times s = String.sub s 9 2, String.sub s 11 2
```

```
let get c =
  let buf = B.create 17 in
  let add = B.add_string buf in
  let events = L.tl (R.split begin_event c) in
  let event e =
    let p = field "CLASS" "PUBLIC\\|PRIVATE" e in
    let t1,t2 = times (field "DTSTART" date e) in
    let s = escape codes (field "SUMMARY" text e) in
    let l = escape codes (field "LOCATION" text e) in
    if p = "PUBLIC" then add " " else add "*";
    add (t1 ^ ":" ^ t2 ^ " ");
    add (wrap s ^ " (" ^ l ^ ")");
    add "\n" in
  L.iter event events;
  B.contents buf
```

Source to View

```
let put a c =
  let is_noop a c = a ^ "\n" = get ("BEGIN:VCALENDAR\nBEGIN:VEVENT" ^ c ^ "END:VCALENDAR\n") in
  let buf = B.create 17 in
  let line s v = B.add_string buf (s ^ ":" ^ wrap v ^ "\n") in
  let c_line s v c = B.add_string buf (s ^ ":" ^ field s v c ^ "\n") in
  let preamble,c_events = match R.split begin_event c with
      [] -> error "ill-formed"
      h::t -> (h,t) in
  let c_assoc = L.map (fun c -> (field "SUMMARY" text c ^ field "LOCATION" text c,c)) c_events in
  let a_events =
    L.map
      (fun a ->
         let p = a.[0] = ' ' in
         let t = (String.sub a 1 2) ^ (String.sub a 4 2) in
         ignore (sch (rx ("[ *][0-9][0-9]:[0-9][0-9] \\(" ^ esctext ^ "\\) (\\(" ^ esctext ^ "\\))")) a 0);
         (p,t,R.matched_group 1 a,R.matched_group 2 a,a))
      (R.split (rx "\n") (unwrap a)) in
  let event dict (p,t,s,l,a) =
    line "BEGIN" "EVENT";
    if p then line "CLASS" "PUBLIC"
    else line "CLASS" "PRIVATE";
    let dict' = match lookup (s ^ l) dict with
        Some (k,c) ->
          let dtstart = field "DTSTART" date c in
          let ymd,s = String.sub dtstart 0 8,String.sub dtstart 13 2 in
          line "DTSTART" (ymd ^ "T" ^ t ^ s ^ "Z");
          c_line "DTEND" date c;
          c_line "DTSTAMP" date c;
          c_line "CREATED" date c;
          if is_noop a c then c_line "LAST-MODIFIED" date c
          else line "LAST-MODIFIED" (today () ^ "T" ^ now () ^ "Z");
          c_line "UID" text c;
          c_line "TRANSP" text c;
          c_line "DESCRIPTION" text c;
          c_line "STATUS" text c;
          c_line "SEQUENCE" text c;
          (remove k dict)
        None ->
          line "DTSTART" (today () ^ "T" ^ t ^ "00Z");
          line "DTEND" (today () ^ "T" ^ t ^ "00Z");
          line "DTSTAMP" (today () ^ "T" ^ now () ^ "Z");
          line "CREATED" (today () ^ "T" ^ now () ^ "Z");
          line "LAST-MODIFIED" (today () ^ "T" ^ now () ^ "Z");
          line "UID" (uid ());
          line "TRANSP" "OPAQUE";
          line "DESCRIPTION" "";
          line "STATUS" "TENTATIVE";
          line "SEQUENCE" "0";
          dict in
    line "SUMMARY" (unescape codes s);
    line "LOCATION" (unescape codes l);
    line "END" "EVENT";
    dict' in
  B.add_string buf preamble;
  let _ = L.fold_left event c_assoc a_events in
  B.add_string buf "END:VCALENDAR\n";
  B.contents buf
```

View to Source

# Comparison: String Lens

## Helpers

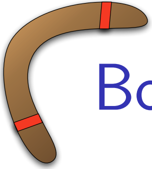
```
let BEGIN_CALENDAR,END_CALENDAR : (regexp * regexp) = "BEGIN:VCALENDAR","END:VCALENDAR"
let BEGIN_EVENT,END_EVENT : (regexp * regexp) = "BEGIN:VEVENT","END:VEVENT"
let PREAMBLE,POSTAMBLE : (regexp * regexp) = (BEGIN_CALENDAR . NL . ( ANY - containing BEGIN_EVENT)),(END_CALENDAR . NL)
let text : lens = Escaping.escape [^\n] #char*string[('\',"\\\\");('(',"\\(");(')',"\\)")]
let TEXT,ESCTEXT : regexp * regexp = ctype text,atype text
let TIME,LOC : regexp * regexp = (DIGIT2 . ":" . DIGIT2), (SPACE . LPAREN . ESCTEXT . RPAREN)

let line (tag:string) (l:lens) : lens = del (tag . ":") . l . del "\n"
let parens (l:lens) : lens = ins "(" . l . ins ")"
let wrapl (l:lens) = left_quot (columnize 75 (ctype l [illegible]
let wrapr (l:lens) = right_quot l (columnize 75 (atype l) [illegible]
let now (s:string) : string = exec "date +%H%M%S | tr -d '\n'"
let today (s:string) : string = exec "date +%Y%m%d | tr -d '\n'"
let uid (s:string) : string = exec "cat /dev/urandom|uuencode -m -|tail +2|tr -dc 'a-zA-Z0-9'|head -c25"
let date (tag:string) (time:regexp -> regexp -> regexp -> lens) : lens =
  line tag (clobber DIGIT8 "" today . del "T" . time DIGIT2 DIGIT2 DIGIT2 . del "Z")
let copy_time (H:regexp) (M:regexp) (S:regexp) : lens = copy H . ins ":" . copy M . del S
let clobber_time (H:regexp) (M:regexp) (S:regexp) : lens = clobber (H . M . S) "" now
```

## Source to View *and* View to Source

```
let event1 : lens =
  del (BEGIN_EVENT . NL) .
  fiat (Sort.sort_concat
    #lens[
      line "CLASS" ("PRIVATE" <-> ASTERISK | "PUBLIC" <-> SPACE)
    ; date "DTSTART" copy_time . ins DASH
    ; date "DTEND" copy_time . ins SPACE
    ; date "DTSTAMP" clobber_time
    ; date "CREATED" clobber_time
    ; date "LAST-MODIFIED" clobber_time
    ; line "UID" (clobber TEXT "" uid)
    ; line "TRANSP" (const TEXT "" "OPAQUE")
    ; line "DESCRIPTION" (del TEXT)
    ; line "STATUS" (const TEXT "" "TENTATIVE")
    ; line "SEQUENCE" (const NUMBER "" "0")
    ; line "SUMMARY" (wrapl (text; key ESCTEXT) . ins SPACE
    ; line "LOCATION" (parens (wrapl (text; key ESCTEXT))) ]) .
  del (END_EVENT) . copy NL
let event2 : lens =
  copy (SPACE | ASTERISK) . merge_with_sep TIME DASH .
  copy SPACE . wrapr (key ESCTEXT . copy LOC) . copy NL
let ical1 : lens = del PREAMBLE . <~ e1:event1 >* . del POSTAMBLE
let ical : lens = ical1; <~ e2:event2 >*
```

[Bohannon, Foster, Pierce, Pilkiewicz, Schmitt POPL '08]
[Foster, Pierce, Pilkiewicz ICFP '08]



# Boomerang

"Good men must not obey
the laws too well"
—R W Emerson

# Challenge: Ignorable Data

Many real-world data formats contain inessential data.

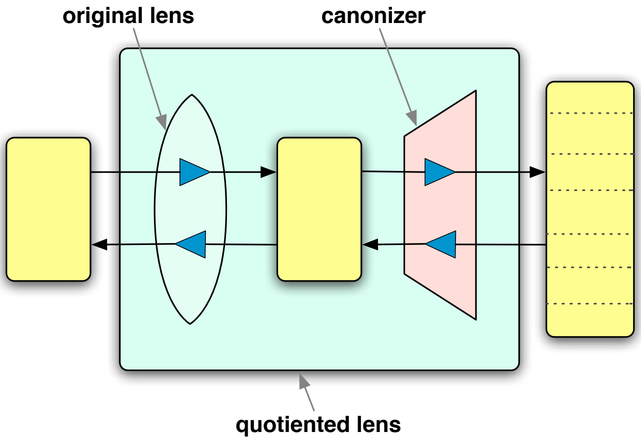
- whitespace, wrapping of long lines of text
- order of fields in record-structured data
- escaping of special characters
- aggregate values, timestamps, etc.

In practice, to handle these details, we need lenses that are well behaved modulo equivalence relations on the source and view.

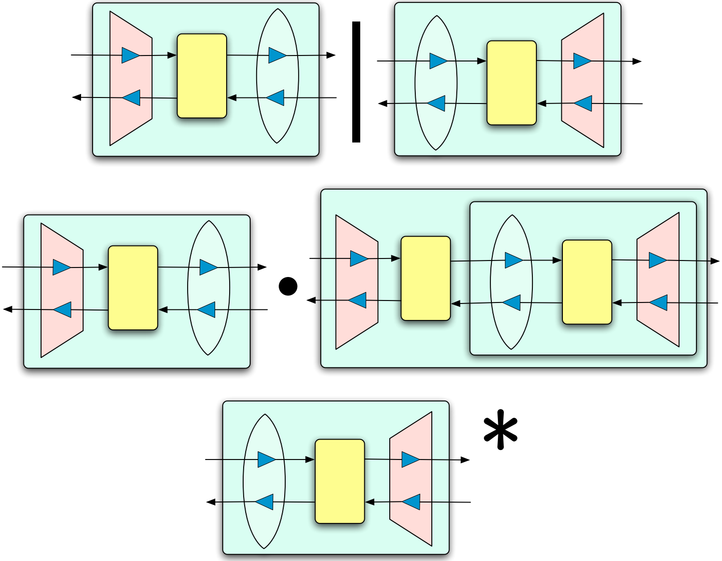
$$l.\mathbf{get}\ (l.\mathbf{put}\ v\ s) \sim_V v \qquad (\textsc{PutGet})$$

$$l.\mathbf{put}\ (l.\mathbf{get}\ s)\ s \sim_S s \qquad (\textsc{GetPut})$$

# Quotient Lenses



# Quotient Lenses



# Challenge: Ordered Data

The lenses we have seen so far align data by position.

But, in practice, we often need to align data according to different criteria—e.g., by key.

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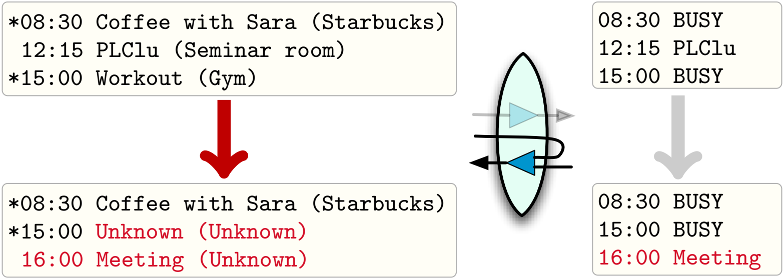

# A Better Redact Lens

Similar to previous version but with a key annotations and a combinator (<l>) that identifies "chunks"

```
(* helper lenses *)
let location : lens = default (del LOCATION) " (Unknown)"

let public : lens =
  del SPACE .
  key TIME .
  copy TEXT .
  default (del LOCATION) " (Unknown)"

let private : lens =
  del ASTERISK .
  key TIME .
  default (TEXT . LOCATION <-> "BUSY") "Unknown (Unknown)" .
let event : lens =
  (public | private) .
  copy NL

(* main lens *)
let redact : lens = <~ event>*
```

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  key TIME .
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let event : lens =
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  copy NL

(* main lens *)
let redact : lens = <~ event>*
```
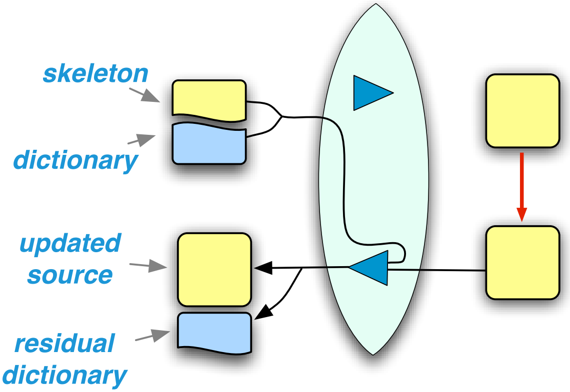

# Dictionary Lenses

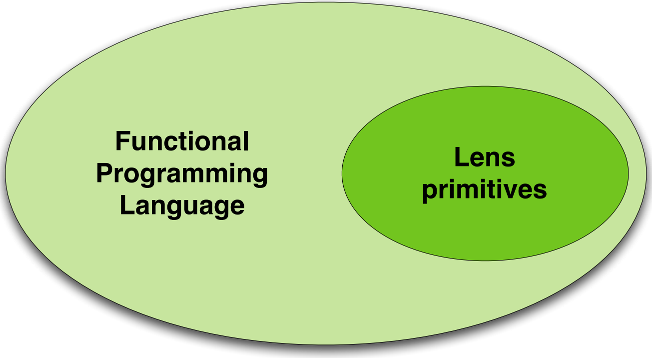



The **put** function works on a dictionary structure where chunks are organized by key.

# Challenge: Language Design

Writing big programs only using combinators would not be fun!

Boomerang is a full-blown functional language over the base types `string`, `regexp`, `lens`, ...



# Additional Features

Boomerang has *many* other lens primitives

- partition
- filter
- permute
- sort
- duplicate
- merge
- sequentially compose
- columnize
- normalize
- clobber
- probe
- etc.

and an extremely rich type system

- regular expression types
- dependent types
- refinement types
- polymorphism
- user-defined datatypes
- modules

implemented in hybrid style [Flanagan '06][Findler, Wadler '09]

# Challenge: Typechecker Engineering

Typechecking uses *many* automata-theoretic operations.

- "Expensive" operations like intersection, difference, and interleaving are used often in practice
- Algorithms for checking ambiguity are computationally expensive rarely implemented

Implementation strategy:

- Compile compact automata [Brzozoswki '64]
- Aggresive memoization [Foster *et al.* PLAN-X '07]

# The Boomerang System

## Lenses

- Bibliographies (BibTeX, RIS)
- Address Books (vCard, XML, ASCII)
- Calendars (iCal, XML, ASCII)
- Scientific Data (SwissProt, UniProtKB)
- Documents (MediaWiki, literate source code)
- Apple Preference Lists (e.g., iTunes)
- CSV

## Libraries

- Escaping
- Sorting
- Lists
- XML

## System

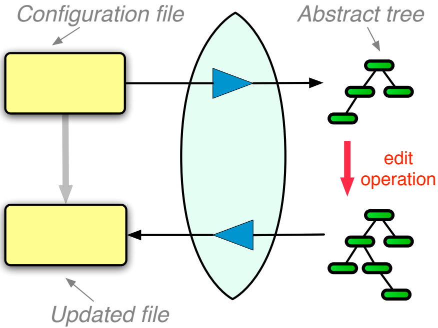
- Stable prototype complete
- Available under LGPL

## Unison Integration

- On the way...

# Boomerang in Industry

"a configuration API."



# Boomerang in Industry

Augeas "a configuration API."

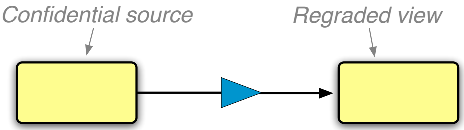
| | | | | |
|---|---|---|---|---|
| aliases.aug | fstab.aug | monit.aug | rsyncd.aug | sysctl.aug |
| aptpreferences.aug | gdm.aug | ntp.aug | samba.aug | util.aug |
| aptsources.aug | group.aug | openvpn.aug | services.aug | vsftpd.aug |
| bbhosts.aug | grub.aug | pam.aug | shellvars.aug | webmin.aug |
| darkice.aug | hosts.aug | passwd.aug | slapd.aug | xinetd.aug |
| dhclient.aug | inifile.aug | php.aug | soma.aug | xorg.aug |
| dnsmasq.aug | inittab.aug | phpvars.aug | spacevars.aug | yum.aug |
| dpkg.aug | interfaces.aug | postfix_main.aug | squid.aug | |
| dput.aug | limits.aug | postfix_master.aug | sshd.aug | |
| exports.aug | logrotate.aug | puppet.aug | sudoers.aug | |

Also used in

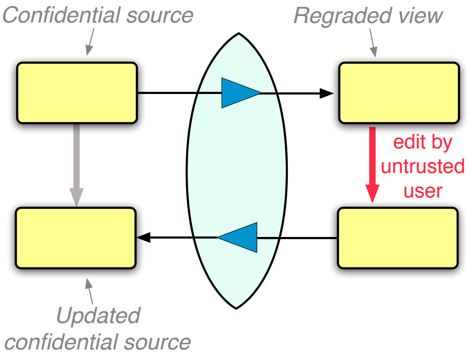
- Puppet – declarative configuration management tool
- Show – SQL-like queries on the filesystem
- Netcf – a network configuration library

# Ongoing Work

# Security Views

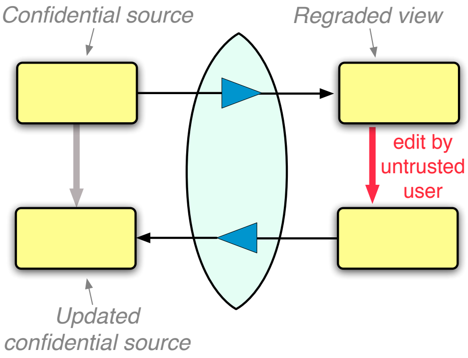


# Updatable Security Views




[Foster, Pierce, Zdancewic CSF '09]

# Requirements for Updatable Security Views

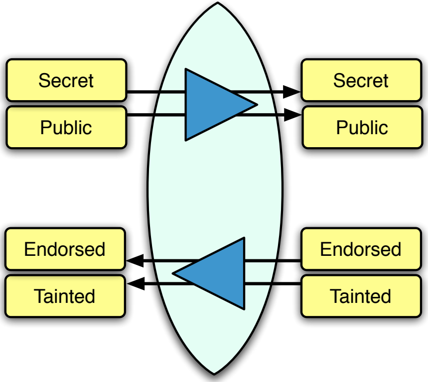



[Foster, Pierce, Zdancewic CSF '09]

1. Confidentiality: **get** does not leak secret data
2. Integrity: **put** does not taint endorsed data

# Non-interference

Requirements can be formulated as non-interference properties.



# Secure Lenses

To distinguish high and low-security data we use equivalences

- $\sim_k$ — "agree on $k$-public data"
- $\approx_k$ — "agree on $k$-endorsed data"

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described using annotated regular expressions.

$$\mathcal{R} ::= \emptyset \mid u \mid \mathcal{R}{\cdot}\mathcal{R} \mid \mathcal{R}|\mathcal{R} \mid \mathcal{R}^* \mid \mathcal{R}:k$$

# Secure Lenses

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$$\mathcal{R} ::= \emptyset \mid u \mid \mathcal{R}{\cdot}\mathcal{R} \mid \mathcal{R}|\mathcal{R} \mid \mathcal{R}* \mid \mathcal{R}:k$$

A secure lens obeys refined laws:

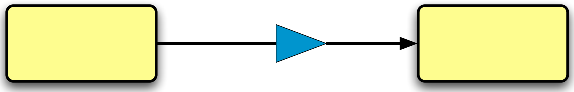
$$\frac{s \sim_k s'}{l.\mathbf{get}\ s \sim_k l.\mathbf{get}\ s'} \qquad (\textsc{GetNoLeak})$$

$$\frac{v \approx_k (l.\mathbf{get}\ s)}{l.\mathbf{put}\ v\ s \approx_k s} \qquad (\textsc{GetPut})$$

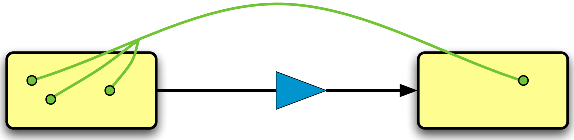
(See paper for a dynamic approach to integrity tracking.)

# Future Directions

# Data Provenance

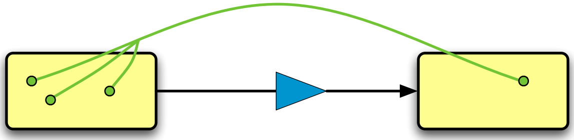


# Data Provenance



Provenance is metadata that describes the origin and causal history of pieces of data.

# Data Provenance

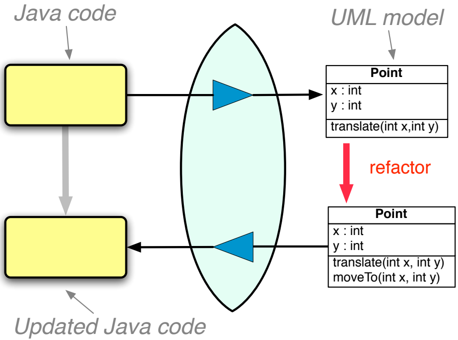


Provenance is metadata that describes the origin and causal history of pieces of data.

In the context of lenses, provenance is useful

- for fine-grained tracking of confidentiality and integrity [Foster, Green, Tannen PODS '08]
- for incremental view maintenance
- as an additional input to the **put** function

# Model Transformations




Much interest in the software engineering community in using lenses for bidirectional model transformations [Stevens '07] [Czarnecki, Foster, Hu, Lämmel, Schürr, Terwilliger ICMT '09]

Requires lenses for richer structures — e.g., graphs.

# Conclusion

"Bidirectional programming languages are an effective and elegant means of describing updatable views"

## Lenses

- Semantic space of well-behaved bidirectional transformations
- Provides foundation for bidirectional languages

## Boomerang

- Language for lenses on strings
- Natural syntax based on regular operators
- Extensions to handle ordered and ignorable data
- Type system guarantees well-behavedness and totality

## Implementation & Applications

- Lenses for a number of real-world formats
- Adoption in Augeas
- Updatable security views

# Thank You!

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Want to play? Boomerang is available for download.

- Source code (LGPL)
- Precompiled binaries for Linux, OS X, Windows
- Research papers
- Tutorial and demos

http://www.seas.upenn.edu/~harmony/