Based on slides by Simon Peyton-Jones, Julian Seward, Jean-Marc Seber

DOMAIN-SPECIFIC LANGUAGES

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Domain-Specific Languages

- Encoding domain expertise
  - Domain abstractions
  - Operations for manipulating abstractions
- Application generators
  - Can customization of generated app be related to original DSL program?
- Prototyping languages
  - E.g. evaluate financial instruments before production implementation

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- RISLA:
  - Standalone domain-specific language
  - Rapid prototyping of financial instruments
  - Object-oriented
  - Compiled to COBOL

```
product LOAN
declaration
  contract data
    PAMOUNT : amount                %% Principal Amount
    STARTDATE : date                %% Starting date
    MATURDATE : date                %% Maturity data
    INTRATE : int-rate              %% Interest rate
    RDMLIST := [] :  cashflow-list  %% List of redemptions.
  information
    PAF : cashflow-list             %% Principal Amount Flow
    IAF : cashflow-list             %% Interest Amount Flow
  registration
    %% Register one redemption.
    RDM(AMOUNT : amount, DATE : date)
  local
    %% Final Principal Amount
    FPA(CHFLLIST : cashflow-list) :  amount
    %% Final redemption
    FRDM : cashflow
  error checks
    "Wrong term dates" in case of STARTDATE >= MATURDATE
    "Negative amount" in case of PAMOUNT < 0.0
implementation
  local
    define FPA as IBD(CHFLLIST, -/-PAMOUNT, MATURDATE)
    define FRDM as <-/-FPA(RDMLIST), MATURDATE>
  information
    define PAF as [<-/-PAMOUNT, STARTDATE>] >> RDMLIST >> [FRDM]
    define IAF as [< -/-CIA( BL(RDMLIST, <-/-PAMOUNT,
                               <STARTDATE, MATURDATE>>),
                             INTRATE ), MATURDATE >]
  registration
    define RDM as
      error checks
        "Date not in interval" in case of (DATUM < STARTDATE)
                               or (DATUM >= MATURDATE)
        "Negative amount"      in case of AMOUNT <= 0.0
        "Amount too big"       in case of
            FPA(RDMLIST >> [<AMOUNT, DATE>]) > 0.0
      RDMLIST := RDMLIST >> [<AMOUNT, DATE>]
```


- Haskell Contracts
  - Embedded domain-specific language
  - Communication among domain experts
  - Declarative
  - Embedded in Haskell functional language

`zero :: Contract`
"`zero` is a contract that may be acquired at any time. It has no rights and no obligations, and has an infinite horizon."

`one :: Currency → Contract`
"`(one k)` is a contract that immediately pays the holder one unit of the currency `k`. The contract has an infinite horizon."

`give :: Contract → Contract`
"To acquire `(give c)` is to acquire all of `c`'s rights as obligations, and vice versa. For a bilateral contract `q` between parties *A* and *B*, *A* acquiring `q` implies that *B* acquires `(give q)`."

`and :: Contract → Contract → Contract`
"If you acquire `c1 'and' c2)` then you immediately acquire both `c1` (unless it has expired) and `c2` (unless it has expired). The composite contract expires when both `c1` and `c2` expire."

`or :: Contract → Contract → Contract`
"If you acquire `c1 'and' c2)` then you immediately acquire either `c1` or `c2` (but not both). If either has expired, that one cannot be chosen. When both have expired, the compound contract expires."

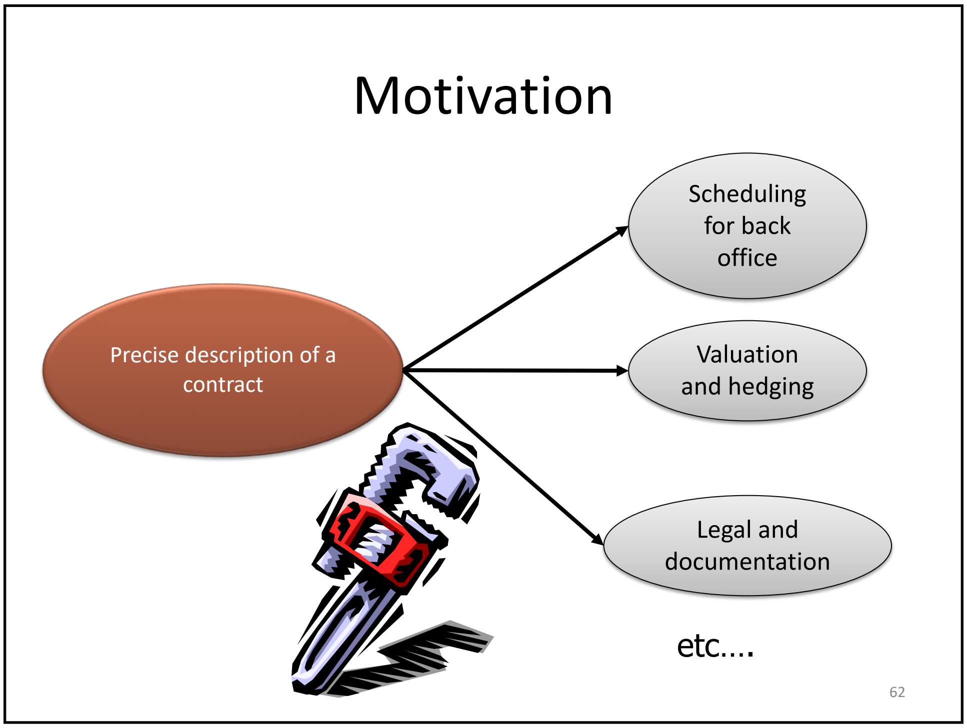
`truncate :: Date → Contract → Contract`
"`(truncate t c)` is exactly like `c` except that it expires at the earlier of `t` and the horizon of `c`. Notice that `truncate` limits only the possible *acquisition date* of `c`; it does not truncate `c`'s rights and obligations, whhich may extend well beyond `t`."

`then :: Contract → Contract → Contract`
"If you acquire `(c1 'then' c2)` and `c1` has not expired, then you acquire `c1`. If `c1` has expired, but `c2` has not, then you acquire `c2`. The compound contract expires when both `c1` and `c2` expire."

`scale :: Obs Double → Contract → Contract`
"If you acquire `(scale o c)`, then you acquire `c` at the same moment, except that all the rights and obligations of `c` are multiplied by the value of the observables `o` at the moment of acquisition."

`get :: Contract → Contract`
"If you acquire `(get c)` then you must acquire `c` at `c`'s expiry date. The compound contract expires at the same moment that `c` expires."

`anytime :: Contract → Contract`
"If you acquire `(anytime c)` you must acquire `c`, but you can do so at any time between the acquisition of `(anytime c)` and the expiry of `c`. The compound contract expires when `c` does."


Motivation
Precise description of a contract
Scheduling for back office
Valuation and hedging
Legal and documentation
etc….
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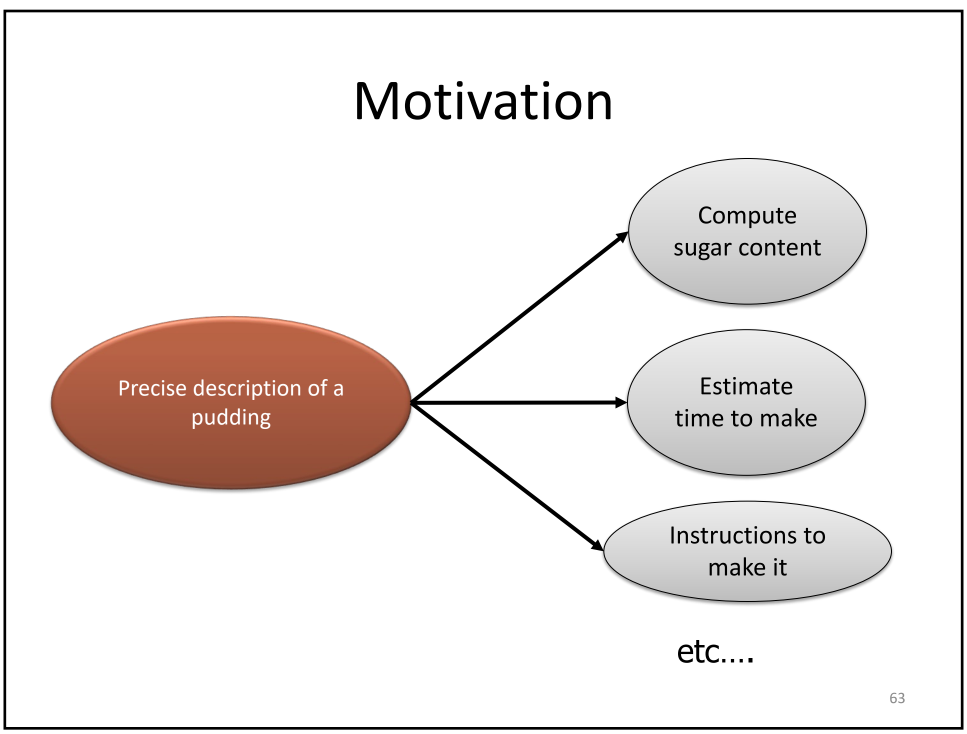
Motivation
Precise description of a pudding
Compute sugar content
Estimate time to make
Instructions to make it
etc….
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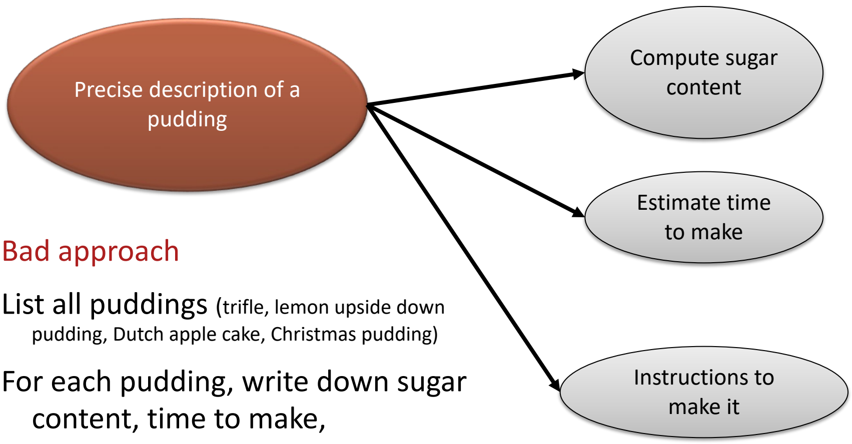
Motivation



Bad approach

List all puddings (trifle, lemon upside down pudding, Dutch apple cake, Christmas pudding)

For each pudding, write down sugar content, time to make, instructions etc

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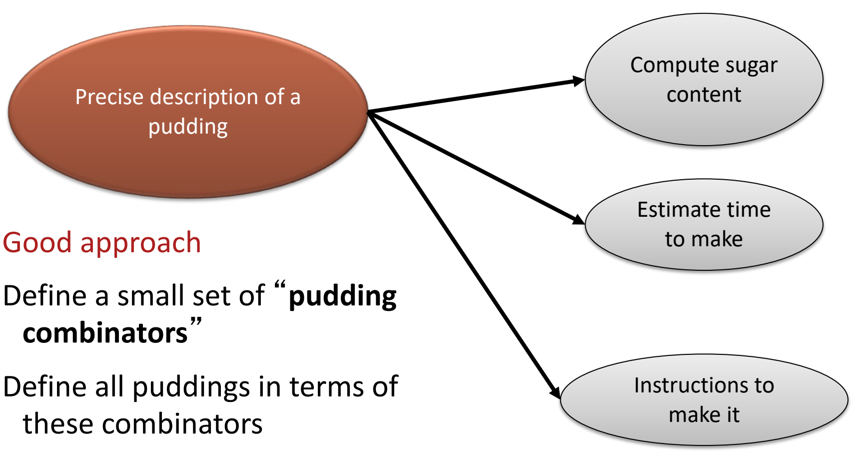
Motivation



Good approach

Define a small set of "**pudding combinators**"

Define all puddings in terms of these combinators

Calculate sugar content from these combinators too

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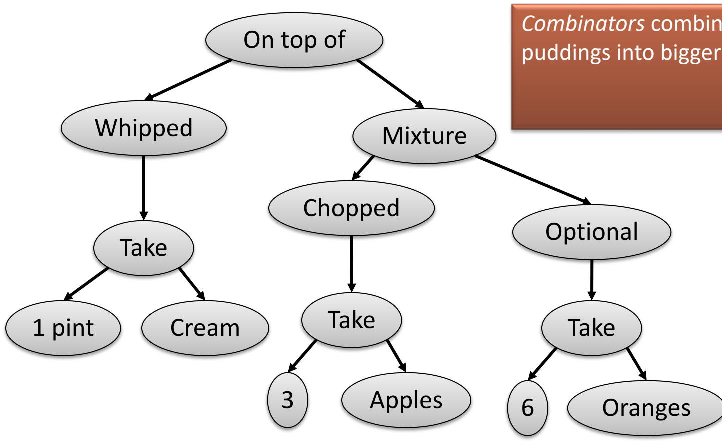
Creamy fruit salad



Combinators combine small puddings into bigger puddings

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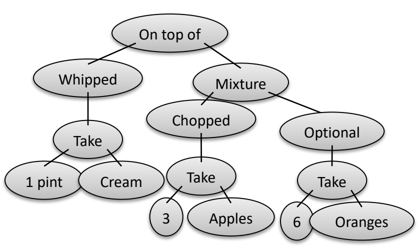
Trees can be written as text



Notation:

`parent child1 child2`

`function arg1 arg2`

```
salad        = onTopOf topping main_part
topping      = whipped (take pint cream)
main_part    = mixture apple_part orange_part
apple_part   = chopped (take 3 apple)
orange_part  = optional (take 6 oranges)
```

Slogan: a domain-specific language for describing puddings

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Building a simple contract

"Receive $100 on 1 Jan 2020"

```
c1 :: Contract
c1 = zcb (date "1 Jan 2020") 100 Dollars
```

```
zcb :: Date → Float → Currency → Contract
-- Zero coupon bond
```

Combinators will appear in gold boxes

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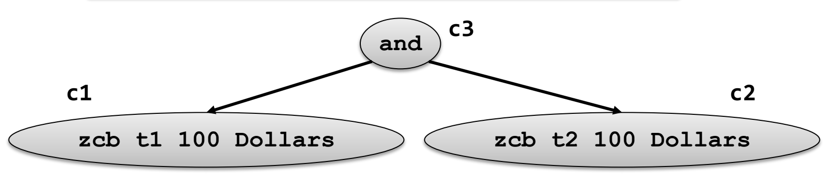
Combining contracts

```
c1,c2,c3 :: Contract
c1 = zcb (date "1 Jan 2020") 100 Dollars
c2 = zcb (date "1 Jan 2021") 100 Dollars

c3 = and c1 c2
```

```
and :: Contract → Contract → Contract
-- Both c1 and c2
```



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Inverting a contract

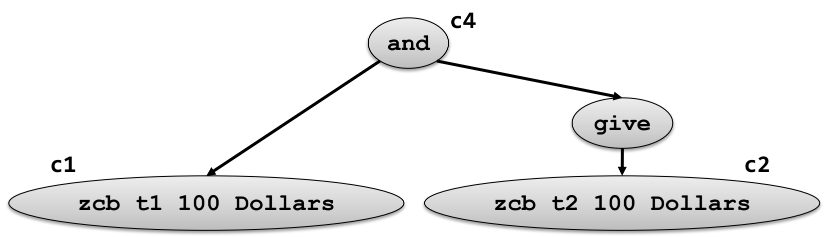
Backquotes for infix notation

```
c4 = c1 `and` give c2
```

```
give :: Contract → Contract
-- Invert role of parties
```

and is like addition

give is like negation



New combinators from old

```
andGive :: Contract → Contract → Contract
andGive u1 u2 = u1 `and` give u2
```

andGive is a new combinator, defined in terms of simpler combinators

To the “user”, **andGive** is no different from a primitive, built-in combinator

This is the key to extensibility: **users can write their own libraries of combinators to extend the built-in ones**

Defining zcb

Indeed, **zcb** is not primitive:

```
zcb :: Date → Float → Currency → Contract
                                 (one Dollar)
```

```
one :: Currency → Contract
-- Receive one unit of currency immediately
```

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Defining zcb

Indeed, **zcb** is not primitive:

```
zcb :: Date → Float → Currency → Contract
                         (scaleK 100 (one Dollar))
```

```
one :: Currency → Contract
-- Receive one unit of currency immediately

scaleK :: Float → Contract → Contract
-- Acquire specified number of contracts
```

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Defining zcb

Indeed, **zcb** is not primitive:

```
zcb :: Date → Float → Currency → Contract
at (Date “1 Jan 2020”) (scaleK 100 (one Dollar))
```

```
one :: Currency → Contract
-- Receive one unit of currency immediately

scaleK :: Float → Contract → Contract
-- Acquire specified number of contracts

at :: Date → Contract → Contract
-- Acquire the contract at specified date
```

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Acquisition dates

```
one :: Currency → Contract
-- Receive one unit of currency immediately

at :: Date → Contract → Contract
-- Acquire the underlying contract at specified date
```

If you acquire the contract **(one k)**, you receive one unit of currency **k immediately**

If you acquire the contract **(at t u)** at time **s<t**, then you acquire the contract **u** at the (later) time **t**.

You cannot acquire **(at t u)** after **t**. The latest acquisition date of a contract is its **horizon**.

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Choice

- An *option* gives the flexibility to:

- **Choose which** contract to acquire
  - as a special case, **whether** to acquire a contract

- **Choose when** to acquire a contract
  - exercising the option = acquiring the underlying contract

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Choose **which**

European option: at a particular date you may choose to acquire an "underlying" contract, or to decline

```
european :: Date → Contract → Contract
european t u = at t (u `or` zero)
```

```
or :: Contract → Contract → Contract
-- Acquire either c1 or c2 immediately

zero :: Contract
-- A worthless contract
```

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Choose **when**: American options

The option to acquire 10 Microsoft shares, for $100, anytime between t1 and t2 years from now

```
anytime :: Contract → Contract
-- Acquire the underlying contract at
-- any time before it expires (but
-- you must acquire it)
```

anytime: Choose *when*

```
golden_handcuff = anytime shares

shares = zero `or` (scaleK -100 (one Dollar) `and`
                    scaleK 10 (one MSShare))
```

or: Choose *whether*

MS shares are a "currency"

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Setting the window

```
golden_handcuff = (anytime shares)
```

```
anytime :: Contract → Contract
-- Acquire the underlying contract at any time
-- before it expires (but you must acquire it)
```

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Setting the window

```
golden_handcuff = (anytime (truncate t2 shares))
```

Can't acquire shares after t2

```
truncate :: Date → Contract → Contract
-- Truncate the horizon of a contract
```

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Setting the window

```
golden_handcuff = at t1
                    (anytime (truncate t2 shares))
```

Acquire the anytime rights at t1

Can't acquire shares after t2

```
truncate :: Date → Contract → Contract
-- Truncate the horizon of a contract

at :: Date → Contract → Contract
-- Acquire the underlying contract at specified date
```

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Observables

Pay me $1000 * (the number of inches of snow - 10) on 1 Jan 2022

```
c :: Contract
c = at "1 Jan 2022" (scale scale_factor (one Dollar))

scale_factor :: Observable
scale_factor = 1000 * (snow - 10)
```

```
scale :: Observable → Contract → Contract
-- Scale the contract by the value of the observable
-- at the moment of acquisition

snow :: Observable
(*), (-) :: Observable → Observable → Observable
```

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But what does it all mean?

- We need an absolutely precise specification of what the combinators mean: their semantics
- And we would like to do something useful with our (now precisely described) contracts
- One very useful thing is to compute a contract's value

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Processing puddings

Wanted: S(P), the sugar content of pudding P

S(`onTopOf p1 p2`)	= S(`p1`) + S(`p2`)
S(`whipped p`)	= S(`p`)
S(`take q i`)	= q * S(i)
...etc...	

When we define a new recipe, we can calculate its sugar content with no further work

Only if we add new combinators or new ingredients do we need to enhance S

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Processing puddings

Wanted: S(P), the sugar content of pudding P

S(`onTopOf p1 p2`)	= S(`p1`) + S(`p2`)
S(`whipped p`)	= S(`p`)
S(take q i)	= q * S(i)
...etc...	

S is ***compositional***

To compute S for a compound pudding,

- Compute S for the sub-puddings
- Combine results in some combinator-dependent way

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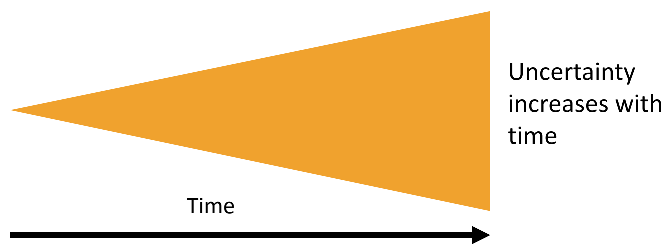
What is the denotation of a contract?

Main idea: the denotation of a contract is a **random process** that models the value of acquiring the contract at that moment.

$\mathcal{E}$: Contract → RandomProcess

RandomProcess = Time → RandomVariable



Compositional valuation

Add random processes point-wise

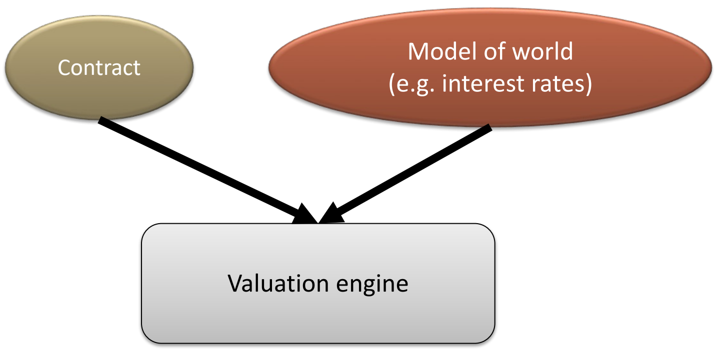
```
Ɛ(c1 `and` c2)      = Ɛ (c1) + Ɛ (c2)
Ɛ(c1 `or` c2)       = max(Ɛ(c1), Ɛ(c2) )
Ɛ(give c)           = - Ɛ (c)
Ɛ(anytime c)        = snell( Ɛ(c) )
Ɛ(at t c)           = discount( Ɛ(c)[t] )
```

…etc…

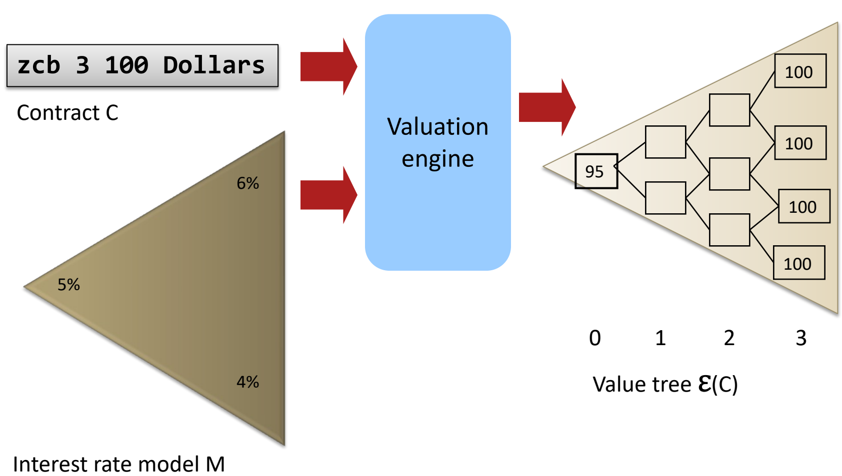
This is a **major payoff**! Deal with the 10-ish combinators, and we are done with valuation!

Valuation

- There are many numerical methods to compute discrete approximations to random processes



Example Evaluation Model: BDT



Reasoning about equivalence

- Using this semantics we can prove (for example) that

```
anytime (anytime c) = anytime c
```

- Depends on algebra of random processes (snell, discount, etc).

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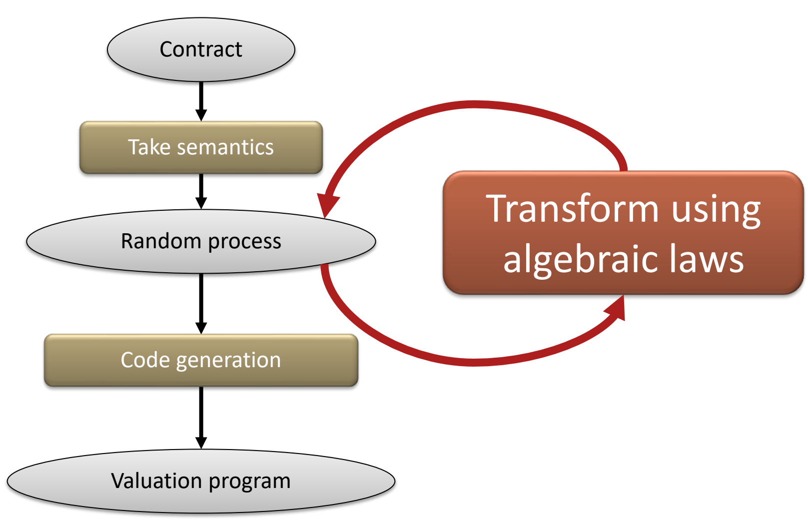
A compiler for contracts



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