# reqT.org – A Scala DSL for Constraint-based Requirement Engineering using JaCoP

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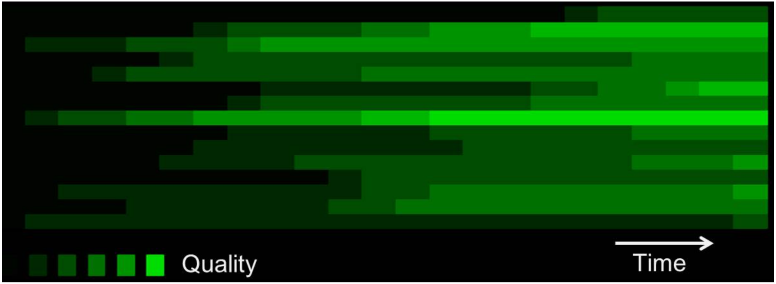
*The 12th Workshop of the Network of Sweden-based researchers and practitioners of Constraint programming, 2013*

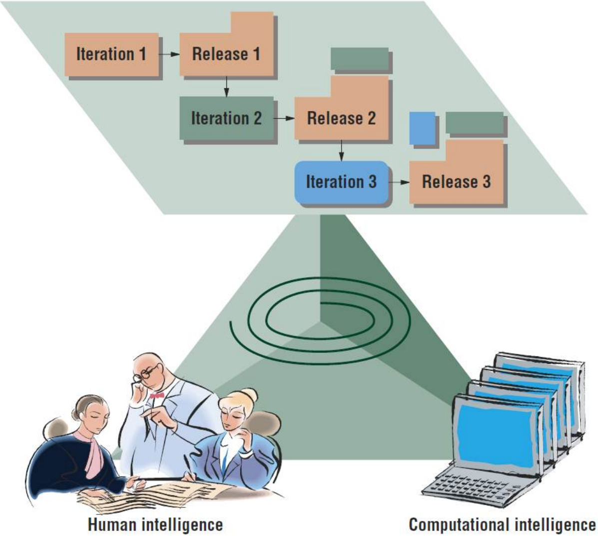
# Software Requirements Engineering




Sub-disciplines of Requirements Engineering (RE):

- **Elicitation**: generating candidate reqts and context knowledge
- **Specification**: documenting candidate reqts
- **Validation**: checking that the (documented) reqts are good enough
- **Prioritization**: assessing candidate reqts based benefit, cost, risk, urgency, ...
- **Selection**: deciding which reqts to implement when, under constraints of *estimated* stakeholder priorities, return-on-investment, inter-dependencies, resource constraints, timing issues, ...

# Release Planning in Software Develepment




[ Ruhe et al.]

# Why Constraint Solving in Requirements Engineering?

Some potential benefits of CSP in RE:

- Flexible specification of decision problems
  - Prioritization
  - Release Planning
- Interactive exploration of the solution space
- Out-of-the-box optimization support


Some challenges:

- How to integrate CSP with RE technology and make it user friendly in the domain?
- How to model CSP problems at the right abstraction level given great uncertainties?

# reqT.org – a Semi-Formal, Open and Scalable Requirements Engineering DSL embedded in Scala

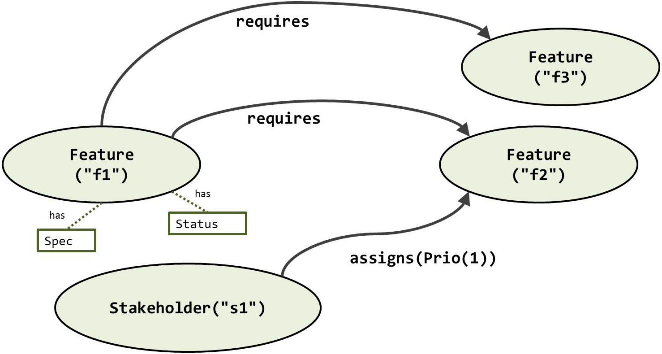
A reqT model includes a sequence of graph parts
<Entity> <Edge> <NodeSet>
separated by comma and wrapped inside a Model( )

```
var myRequirements =  Model(
  Feature("f1") has (Spec("A good spec."), Status(SPECIFIED)),
  Feature("f1") requires (Feature("f2"), Feature("f3")),
  Stakeholder("s1") assigns(Prio(1)) to Feature("f2")
)
```

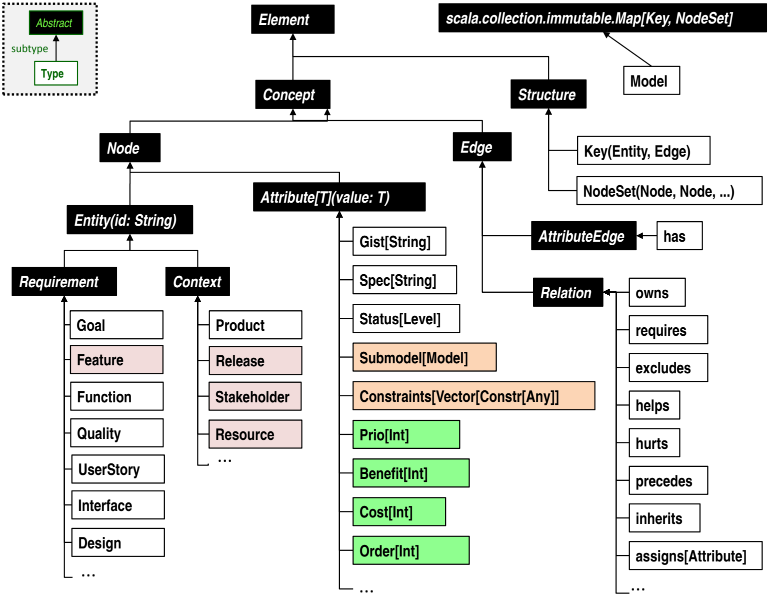
Download: `http://reqT.org`
Source code: `https://github.com/reqT/reqT`

# reqT models are graph structures with Entities & Attributes (nodes) and Relations (edges)

```
var myRequirements =  Model(
  Feature("f1") has (Spec("A good spec."), Status(SPECIFIED)),
  Feature("f1") requires (Feature("f2"), Feature("f3")),
  Stakeholder("s1") assigns(Prio(1)) to Feature("f2")
)
```



# Overview of the reqT metamodel



# reqT models can be hierarchical with recursive submodels in a tree structure

```
var myReqs = Model(
  Feature("nice") has Spec("this is a nice feature"),
  Feature("cool") has Spec("this is a cool feature"),
  Stakeholder("Anna") has Submodel(
    Feature("nice") has Prio(1),
    Feature("cool") has Prio(2)
  ),
  Stakeholder("Martin") has Submodel(
    Feature("nice") has Prio(2),
    Feature("cool") has Prio(1)
  )
)
```

# reqT can reference values of attribute in deeply nested submodel structures using the ! operator

```
Feature("f")!Prio == Ref[Int](Vector(Feature(f)),Prio)
Stakeholder("a")!Feature("g")!Benefit ==
  Ref[Int](Vector(Stakeholder(a),Feature(g)),Benefit)
```

```
val m = Model(
  Feature("f") has Prio(1),
  Stakeholder("a") has Submodel(
    Feature("g") has Benefit(2),
    Resource("x") has Submodel(
      Feature("h") has Cost(3)
    )
  )
)

m(Feature("f")!Prio) == 1
m(Stakeholder("a")!Feature("g")!Benefit) == 2
m(Stakeholder("a")!Resource("x")!Feature("h")!Cost) == 3
```

# reqT includes a Scala-embedded DSL for CSP that wraps the JaCoP solver

- The DSL uses Scala immutable case classes
- The search is set up using JaCoP when calling `solve`
- The search is controlled by parameters to `solve`
- Search results can be accessed through a `scala.collection.immutable.Map`

```
result.lastSolution(Var("x"))
```

# Constraint-based **Priority Ranking** example: 5 features ranked from 1 to 5

reqT:

```
val n = 5
var f = vars(n, "f")
val Result(conclusion, nSol, sol, _ , _) =
  Constraints(
    f::{0 until n},
    AllDifferent(f),
    f(0) #> f(1),
    f(1) #> f(2),
    f(2) #< f(3),
    forAll(0 until n) { f(4) #>= f(_) }
  ).solve(Satisfy)
```

MiniZinc:

```
int: n = 5;
array[1..n] of var 1..n: f;
constraint
  alldifferent(f);
constraint f[1] > f[2];
constraint f[2] > f[3];
constraint f[3] < f[4];
constraint
  forall ( i in 1..n)
    ( f[5] >= f[i] );
solve satisfy;
```

# reqT includes a Scala-embedded DSL for constraints over integer variables

Some key parts of the implementation in Scala:

```
Var("x") #== Var("y")      //>  reqt.XeqY[String] = XeqY(Var(x),Var(y))

case class Var[+T](ref: T)

implicit def refToVar[T](r: Ref[T]): Var[Ref[T]] = Var(r)

case class Interval(min: Int, max: Int)

implicit def rangeToInterval(r: Range): Interval = Interval(r.min, r.max)

def vars[T <: AnyRef](vs: T *): Vector[Var[T]] = vs.map(Var(_)).toVector

def vars(n: Int, prefix: String): Vector[Var[String]] =
  (for (i <- 0 until n) yield Var(s"$prefix$i")).toVector

def forAll[T](xs:Seq[T])(f: T => Constr[_]) = And(xs.map(f(_)).toVector)
```

# reqT CSP: parameters to solve

```scala
def solve[T](
   objective: Objective = Satisfy,
   timeOutOption: Option[Long] = None,
   solutionLimitOption: Option[Int] = None,
   valueSelection: ValueSelection = jacop.IndomainRandom,
   variableSelection: VariableSelection = jacop.InputOrder,
   assignOption: Option[Seq[Var[T]]] = None
): Result[T]

sealed trait Objective
case object Satisfy extends Objective
case object CountAll extends Objective
case object FindAll extends Objective
sealed trait Optimize[+T] extends Objective { def cost: Var[T] }
case class Minimize[+T](cost: Var[T]) extends Optimize[T]
case class Maximize[+T](cost: Var[T]) extends Optimize[T]
```

# reqT CSP: Result and Solutions

```
case class Result[T](
  conclusion: Conclusion,
  solutionCount: Int = 0,
  lastSolution: Map[Var[T], Int] = Map[Var[T], Int](),
  interuptOption: Option[SearchInterupt] = None,
  solutionsOption: Option[Solutions[T]] = None
)

sealed trait Conclusion
case object SolutionFound extends Conclusion
case object SolutionNotFound extends Conclusion
case object InconsistencyFound extends Conclusion
case class SearchFailed(msg: String) extends Conclusion

class Solutions[T](   //the only non-case class (jacop mutability propagates)
        val jacopDomains: Array[Array[JaCoP.core.Domain]],
        val jacopVariables: Array[_ <: JaCoP.core.Var],
        val nSolutions: Int,
        val lastSolution: Map[Var[T], Int]) {
  def solutionMap(s: Int): Map[Var[T], Int] = ...
  def printSolutions: Unit = ...
  ...
}
```

# reqT Entities can have a Constraints attribute containing a sequence of constraints.

```
var myReqs = Model(
  Feature("nice") has Spec("this is a nice feature"),
  Feature("cool") has Spec("this is a cool feature"),
  Stakeholder("Anna") has Constraints(
    (Feature("nice")!Prio) #< 10,
    (Feature("nice")!Prio) #>= 1,
    (Feature("cool")!Prio)::{2 to 7}
  ),
  Stakeholder("Martin") has Constraints(
    (Feature("nice")!Prio) #< 3,
    (Feature("nice")!Prio) #!= 1,
    (Feature("cool")!Prio)::{5 to 10}
  )
)
```

# reqT Release Planning Input Data Model

```
val m = Model(
  Stakeholder("kalle") has (Prio(10), Submodel(
    Feature("F1") has Benefit(20),
    Feature("F2") has Benefit(20),
    Feature("F3") has Benefit(20)
  )),
  Stakeholder("stina") has (Prio(20), Submodel(
    Feature("F1") has Benefit(5),
    Feature("F2") has Benefit(15),
    Feature("F3") has Benefit(35)
  )),
  Resource("developer") has Submodel(
    Release("a") has Capacity(100),
    Release("b") has Capacity(100),
    Feature("F1") has Cost(10),
    Feature("F2") has Cost(70),
    Feature("F3") has Cost(20)
  ),
  Resource("tester") has Submodel(
    Release("a") has Capacity(100),
    Release("b") has Capacity(100),
    Feature("F1") has Cost(40),
    Feature("F2") has Cost(10),
    Feature("F3") has Cost(50)
  ),
  Release("a") has Order(1),
  Release("b") has Order(2)
)
```

# reqT Release Planning: Vectors of Input Entities to prepare imposed constraints

```scala
val features = (m.flatten / Feature).sourceVector
val releases = (m / Release).sourceVector
val resources = (m / Resource).sourceVector
val stakeholders = (m / Stakeholder).sourceVector

val constraints = ???    // to be defined
val utility =  ???       // to be defined

val (m2, r) = Model().impose(constraints).solve(Maximize(utility))
```

# reqT Release Planning: Assign values from Model

The `XeqC` case class constraint, that can be constructed by the `#==` infix operator on `Var`, is used to make a sequence of constraints that grounds integer variables to release planning input data from a reqT `Model`.

```
def assignValuesFromModel(m: Model) =
  Constraints(
    stakeholders.map(s => Var(s!Prio) #== m(s!Prio))  ++
    releases.map(r => Var(r!Order) #== m(r!Order)) ++
    ( for (s <- stakeholders; f <- features) yield
      Var(s!f!Benefit) #== m(s!f!Benefit)) ++
    ( for (res <- resources; f <- features) yield
      Var(res!f!Cost) #== m(res!f!Cost)) ++
    ( for (res <- resources; rel <- releases) yield
      Var(res!rel!Capacity) #== m(res!rel!Capacity))
  )
```

# reqT Release Planning Constraints 1(9)

All Features shall have an Order integer attribute to model that it can be allocated to some Release (corresponding to the Order attribute of that Release).

```
features.map(f => (f!Order)::{1 to releases.size})
```

# reqT Release Planning Constraints 2(9)

For all stakeholders s and all features f:
Var(benefit(s,f)) is the benefit of the feature according to that stakeholder multiplied with the priority of the stakeholder.

```
for (s <- stakeholders; f <- features) yield
  XmulYeqZ(
    Var(s!f!Benefit), Var(s!Prio), Var(s"benefit($s,$f)")
  )
```

# reqT Release Planning Constraints 3(9)

For all features f, for all stakeholders s:
Var(benefit(f)) is the sum of all stakeholders' benefits of that f:

$$\mathit{benefit}(f) = \sum_{s} \mathit{benefit}(s, f)$$

```
features.map(f =>
  Sum(
    stakeholders.map(s =>  Var(s"benefit($s,$f)")),
    Var(s"benefit($f)")
  )
)
```

# reqT Release Planning Constraints 4(9)

for all releases r, for all features f:
**if** f is allocated to r **then** *benefit*$(r, f)) =$ *benefit*$(f)$
**else** *benefit*$(r, f)) = 0$

```
for (r <- releases; f <- features) yield
  IfThenElse(
    Var(f!Order) #== Var(r!Order),
    Var(s"benefit($r,$f)") #== Var(s"benefit($f)"),
    Var(s"benefit($r,$f)") #== 0
  )
```

# reqT Release Planning Constraints 5(9)

For all releases r, for all features f:

$$totBenefit(r) = \sum_{f} benefit(r, f)$$

```
for (r <- releases) yield
  Sum(
    features.map(f => Var(s"benefit($r,$f)")),
    Var(s"totBenefit($r)")
  )
```

# reqT Release Planning Constraints 6(9)

For all releases rel, for all features f, for all resources res:
If f is allocated to rel then `cost(rel, f, res)` is the cost of that feature needed by that resource, else it is zero.

```
for (rel <- releases; f <- features; res <- resources) yield
    IfThenElse(
      Var(f!Order) #== Var(rel!Order),
      Var(s"cost($rel,$f,$res)") #== Var(res!f!Cost),
      Var(s"cost($rel,$f,$res)") #== 0
  )
```

# reqT Release Planning Constraints 7(9)

For all resources res, for all releases rel, for all features f:

$$\mathit{totCost}(\mathit{rel}, \mathit{res}) = \sum_{f} \mathit{cost}(\mathit{rel}, f, \mathit{res})$$

```
for (res <- resources; rel <- releases) yield
  Sum(
    features.map(f => Var(s"cost($rel,$f,$res)")),
    Var(s"totCost($rel,$res)")
  )
```

# reqT Release Planning Constraints 8(9)

For all resources res, for all releases rel:

$$\textit{totCost}(\textit{rel}, \textit{res}) <= \textit{availableCapacity}(\textit{res}, \textit{rel})$$

```
for (res <-resources; rel <- releases) yield
  XlteqY(
    Var(s"totCost($rel,$res)"),
    Var(res!rel!Capacity)
  )
```

# reqT Release Planning Constraints 9(9)

For all releases rel, for all resources res:

$$\mathit{totCost}(\mathit{rel}) = \sum_{\mathit{res}} \mathit{totCost}(\mathit{rel}, \mathit{res})$$

```
for (rel <- releases) yield
  Sum(
    resources.map(res => Var(s"totCost($rel,$res)")),
    Var(s"totCost($rel)")
  )
```

# reqT Release Planning: All 9 Constraints

```
val releasePlanningConstraints =  Constraints(
  features.map(f => Var(f!Order)::{1 to releases.size}) ++
  ( for (s <- stakeholders; f <- features) yield
    XmulYeqZ(Var(s!f!Benefit), Var(s!Prio), Var(s"benefit($s,$f)"))) ++
  features.map(f => Sum(stakeholders.map(s =>
      Var(s"benefit($s,$f)")), Var(s"benefit($f)"))) ++
  ( for (r <- releases; f <- features) yield
    IfThenElse(Var(f!Order) #== Var(r!Order),
      Var(s"benefit($r,$f)") #== Var(s"benefit($f)"),
      Var(s"benefit($r,$f)") #== 0)) ++
  ( for (r <- releases) yield
    Sum(features.map(f => Var(s"benefit($r,$f)")), Var(s"totBenefit($r)"))) ++
  ( for (rel <- releases; f <- features; res <- resources) yield
    IfThenElse(Var(f!Order) #== Var(rel!Order),
      Var(s"cost($rel,$f,$res)") #== Var(res!f!Cost),
      Var(s"cost($rel,$f,$res)") #== 0)) ++
  ( for (res <- resources; rel <- releases) yield
    Sum(features.map(f => Var(s"cost($rel,$f,$res)")), Var(s"totCost($rel,$res)"))) ++
  ( for (res <-resources; rel <- releases) yield
    XlteqY(Var(s"totCost($rel,$res)"), Var(res!rel!Capacity))) ++
  ( for (rel <- releases) yield
    Sum(resources.map(res => Var(s"totCost($rel,$res)")), Var(s"totCost($rel)")))
)
```

# reqT Release Planning Optimization

```
val constraints =
  assignValuesFromModel(m) ++
  releasePlanningConstraints
val utility = Var("totBenefit(Release(a))")
val (m2, r) =
  Model().impose(constraints).solve(Maximize(utility))
```

```
reqT> val allocationModel = m2 / Feature
allocationModel: reqt.Model =
Model(
  Feature("F3") has Order(1),
  Feature("F1") has Order(2),
  Feature("F2") has Order(2)
)

reqT> val cost = r.lastSolution(Var("totCost(Release(a))"))
cost: Int = 70
```

# reqT Release Planning:
# Adding coupling and precedence constraints

**Coupling:** Two features must be in the same release:

```
(Feature("F1")!Order) #== (Feature("F2")!Order)
```

**Precedence:**
One features must be implemented before another feature:

```
(Feature("F2")!Order) #< (Feature("F3")!Order)
```

# Conclusions and Discussion

ReqT integrates RE with CSP using an object-functional embedded DSL to solve decision and resource allocation problems in software engineering.

- Some results so far:
  - Basic DSL in place using immutable Scala case classes
  - Hiding: variable – store dependencies, mutability etc.
  - Integration with JaCoP search parameters, including time-out and solutions limit
- Outlook on future work:
  - More complete implementation of JaCoP 4.0 constraints
  - GUI support (MSc Thesis: Oskar Präntare & Joel Johansson)
  - Soft constraints
  - Stochastic constraints

**Any feedback, question, input etc. welcome!!**

**http://reqT.org**