Reasoning with Goal Models

The problem
Qualitative approach
Quantitative approach
Examples + Exercise

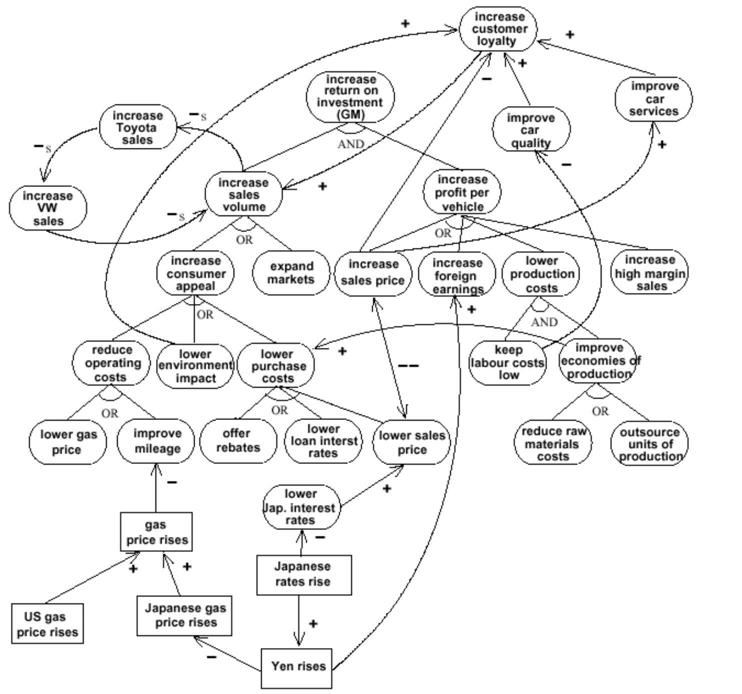
Reasoning with Goal Models

- Stuctures representing goals and goal relationships
- They can be used for modeling
  - stakeholders' goals (early requirements),
  - system's functional and non-functional req.s (late requirements)
  - architectural qualities (architectural and detailed design)
- Allow for vaguely/partially defined goals
  "*The system has to be user-friendly*"
- Allow for vaguely/partially defined goals relations
  "*Car quality contributes positively to customer loyalty*"

Boolean (and/or decomposition) models
are not expressive enough

Goal Graphs

- Goal Dependency Graph:
  - Goals represented as Nodes
  - And/or relationships as (grouped) and/or arcs
  - Identity/negation as ++/- - arcs
  - Positive/negative contribution as +/- arcs
- Cycles possible!



Reasoning with Goal Models (cont.)

Domain knowledge

- (Initial) Valuation(s) of Goals (satisfaction/denial)
- Provided by the domain expert(s)
- Vague/partial goal valuations
  - *"We likely Expand markets"*
- Possibly inconsistent goal valuations
  - "*We likely expand markets" (Marketing Manager),*
  - *"We will surely not expand markets" (Financial Manager)*

Boolean values not expressive enough

Goal Valuations

Goal Valuations:

- Goals can be either satisfied or denied
  - need to represent evidence of satisfaction/denial
- Relationships propagate satisfaction and denial values
  - AND, OR, ++, --: standard semantics
  - + and -?
- Conflicts possible!

The problem

Provide:

- Formal representation(s) of goal models
- Formal representation(s) of goal valuations
- Formal techniques to reason on goal values and on their propagation through goal models

- Qualitative approach
- Quantitative approach

Total and Partial Satisfaction/Denial

- Four predicates: $FS(g)$, $FD(g)$, $PS(g)$, $PD(g)$: “there is at least *F*ull/*P*artial evidence that g is *S*atisfied/*D*enied”
- Full satisfaction/denial implies partial satisfaction/denial:

  $FS(g) \Rightarrow PS(g)$

  $FD(g) \Rightarrow PD(g)$
- Intuition: $PS()$ and $PD()$ come from + and – relations
- Negated atoms $\neg FS(g)$, $\neg FD(g)$ not admitted!
- $FS(g)/PS(g)$ independent from $FD(g)/PD(g)$, (conflict) E.g., g can be fully satisfied and partially denied

Axiomatization

Goal	Invariant Axioms
g	$FS(g) \rightarrow PS(g)$
	$FD(g) \rightarrow PD(g)$

Axiomatization

Goal Relation	Relation Axioms
$(G2,G3) \xrightarrow{and} G1$:	$(FS(G2) \wedge FS(G3)) \rightarrow FS(G1)$
	$(PS(G2) \wedge PS(G3)) \rightarrow PS(G1)$
	$FD(G2) \rightarrow FD(G1),\ FD(G3) \rightarrow FD(G1)$
	$PD(G2) \rightarrow PD(G1),\ PD(G3) \rightarrow PD(G1)$
$G2 \xrightarrow{++S} G1$:	$FS(G2) \rightarrow FS(G1),\ PS(G2) \rightarrow PS(G1)$
$G2 \xrightarrow{--S} G1$:	$FS(G2) \rightarrow FD(G1),\ PS(G2) \rightarrow PD(G1)$
$G2 \xrightarrow{+S} G1$:	$FS(G2) \rightarrow PS(G1),\ PS(G2) \rightarrow PS(G1)$
$G2 \xrightarrow{-S} G1$:	$FS(G2) \rightarrow PD(G1),\ PS(G2) \rightarrow PD(G1)$

Axiomatization (cont.)

- or, +D, -D, ++D, --D dual w.r.t. and, +S, -S, ++S, --S
- Propagation of satisfaction through a ++, --, +, - may be or may be not symmetric w.r.t. that of denail:

  $G2 \xrightarrow{+} G1 \Leftrightarrow G2 \xrightarrow{+S} G1 \text{ and } G2 \xrightarrow{+D} G1$

  $G2 \xrightarrow{-} G1 \Leftrightarrow G2 \xrightarrow{-S} G1 \text{ and } G2 \xrightarrow{-D} G1$

  …
- Initial (partial) valuations are (possibly contradictory) lists of atoms:

  $\{FS(G1), PD(G2), \ldots\}$

Qualitative approach

- *g* is totally satisfied [resp. partially satisfied, totally/partially denied] iff *FS(g)* [resp. *PS(g), FD(g), PD(g)*] can be logically inferred from the initial assignment and the axioms
- *FS(g)*, *PS(g)* and *FD(g)*, *PD(g)* propagated independently
- Axioms and initial assignments are Boolean Horn clauses

⇒ propagation terminates in polynomial time

Propagation Algorithm

```
label_array Label_Graph(graph ⟨G,R⟩,label_array Initail)
  Current=Initial;
  do
    Old=Current;
     for each Gi ∈ G do
        Current[i]=Update_label(i,⟨G,R⟩,Old);
  until not (Current==Old);
  return Current;

label Update_label(int i, graph ⟨G,R⟩,label_array Old)
   for each Rj ∈ R  s.t. target(Ri)== Gi do
      satij = Apply_Rules_Sat(Gi,Rj,Old)
      denij = Apply_Rules_Den(Gi,Rj,Old)
   return ⟨max(maxj(satij),Old[i].sat),
             max(maxj(denij),Old[i].den)⟩
```


Propagation Algorithm (cont.)

- To each *g* we associate two variables *Sat(g)* and *Den(g)* ranging in *{F,P,N}* such that F>P>N
- E.g., $Sat(g) \geq P$ states that there is at least partial evidence that *g* is satisfiable
- From the initial assignment, we propagate the values according to the following rules:

	$(G_2, G_3) \overset{and}{\longmapsto} G_1$	$G_2 \overset{+}{\longmapsto} G_1$	$G_2 \overset{-}{\longmapsto} G_1$	$G_2 \overset{++}{\longmapsto} G_1$	$G_2 \overset{--}{\longmapsto} G_1$
$Sat(G_1)$	$min\{Sat(G_2), Sat(G_3)\}$	$min\{Sat(G_2), P\}$	N	$Sat(G_2)$	N
$Den(G_1)$	$max\{Sat(G_2), Sat(G_3)\}$	N	$min\{Sat(G_2), P\}$	N	$Sat(G_2)$

- or, +D, -D, ++D, --D dual w.r.t. and, +S, -S, ++S, --S
- Satisfaction/denial values monotonically non-decreasing
- Terminates when reaches a fixpoint (*Current==Old*)

Quantitative Approach

- Evidence of satisfaction/denial represented by real values in $\mathcal{D}: [inf,sup]$, $0 \leq inf < sup$
- Value propagation through goal graphs as math functions, $fr : \mathcal{D}^n \rightarrow \mathcal{D}$
- Much finer-grained:
  - Different degrees of satisfaction/denial evidence
  - Different degrees of positive/negative contribution
  - Different strength of conflicts

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Numerical representation of evidence

- $Sat(g), Den(g) \in [inf,sup]$
- Atoms in the form $Sat(g) \geq c_1$ [$Den(g) \geq c_2$]: “there is at least an evidence c_1 [c_2] that g is Satisfied [Denied]”

$$c_1 = inf, c_2 = inf \Leftrightarrow \top$$

$$c_1, c_2 \in]inf,sup] \Leftrightarrow PS(g), PD(g)$$

$$c_1 = sup, c_2 = sup \Leftrightarrow FS(g), FD(g)$$

- *Conflict:* $Sat(g) \geq c_1$ and $Den(g) \geq c_2$, $c_1, c_2 \in]inf,sup]$

Value propagation model

- 2 dual OPERATORS: ⊕ and ⊗, representing value propagation trough "or" and "and"
  - Independent probability model:
    $inf=0, sup=1$
    $p_1 \oplus p_2 = p_1+p_2 - p_1 \cdot p_2$
    $p_1 \otimes p_2 = p_1 \cdot p_2$
  - *Flow model* (Resistor):
    $inf=0, sup = +\infty$
    $v_1 \oplus v_2 = v_1+v_2$
    $v_1 \otimes v_2 = (v_1 \cdot v_2)/(v_1+v_2)$
  - …

Axiomatization

Goal Relation	Relation Axioms
$(G2,G3) \xrightarrow{and} G1$:	$(Sat(G2)\geq x \wedge Sat(G3) \geq y) \rightarrow Sat(G1)\geq (x \otimes y)$ $(Den(G2)\geq x \wedge Den(G3) \geq y) \rightarrow Den(G1)\geq (x \oplus y)$
$G2 \xrightarrow{w+S} G1$:	$Sat(G2)\geq x \rightarrow Sat(G1)\geq (x \otimes w)$
$G2 \xrightarrow{w-S} G1$:	$Sat(G2)\geq x \rightarrow Den(G1)\geq (x \otimes w)$
$G2 \xrightarrow{++S} G1$:	$Sat(G2)\geq x \rightarrow Sat(G1)\geq x$
$G2 \xrightarrow{--S} G1$:	$Sat(G2)\geq x \rightarrow Den(G1)\geq x$

- or, +D, -D, ++D, --D dual w.r.t. and, +S, -S, ++S, --S
- Remark: + and - relations have a weight w

Quantitative approach

- There is at least an evidence c that g is satisfied [resp. denied] iff $Sat(g) \geq c$ [resp. $Den(g) \geq c$] can be logically inferred from the initial assignment and the axioms.
- $Sat(g) \geq c, Den(g) \geq c$ propagated independently

Propagation Algorithm

```
label_array Label_Graph(graph ⟨G,R⟩,label_array Initail)
  Current=Initial;
  do
    Old=Current;
     for each Gi ∈ G do
        Current[i]=Update_label(i,⟨G,R⟩,Old);
  until not (||Current – Old||∞ ≤ ε);
  return Current;

label Update_label(int i, graph ⟨G,R⟩,label_array Old)
   for each Rj ∈ R  s.t. target(Ri)== Gi do
      satij = Apply_Rules_Sat(Gi,Rj,Old)
      denij = Apply_Rules_Den(Gi,Rj,Old)
    return ⟨max(maxj(satij),Old[i].sat),
              max(maxj(denij),Old[i].den)⟩
```

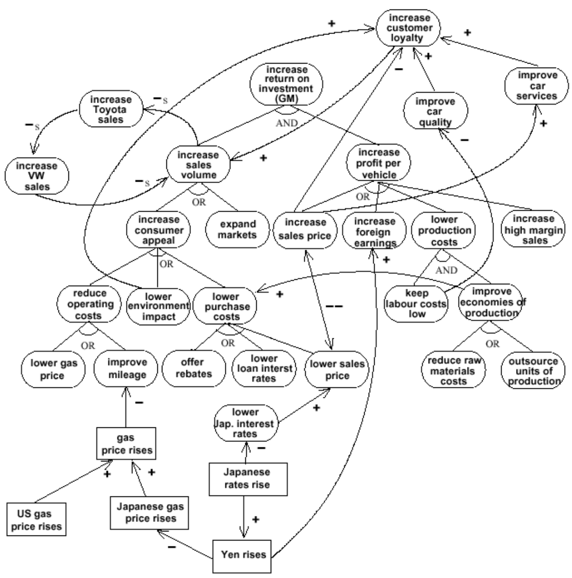
Propagation Algorithm (cont.)

	$(G_2, G_3) \overset{and}{\longmapsto} G_1$	$G_2 \overset{w+}{\longmapsto} G_1$	$G_2 \overset{w-}{\longmapsto} G_1$	$G_2 \overset{++}{\longmapsto} G_1$	$G_2 \overset{--}{\longmapsto} G_1$
$Sat(G_1)$	$Sat(G_2) \otimes Sat(G_3)$	$Sat(G_2) \otimes w$		$Sat(G_2)$	
$Den(G_1)$	$Den(G_2) \oplus Den(G_3)$		$Sat(G_2) \otimes w$		$Sat(G_2)$

- Satisfaction/denial values monotonically non-decreasing
- Uses Cauchy-convergence as termination condition:

$$|a_{n+1} - a_n| \to 0$$

$$n \to \infty$$



Qualitative approach: example

Goals/Events	Exp 1				Exp 2				Exp 3				Exp 4			
	Init		Fin		Init		Fin		Init		Fin		Init		Fin	
	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D
increase return on investment (GM)	N	N	N	P	N	N	P	P	N	N	F	N	N	N	F	P
increase sales volume	N	N	F	N	N	N	F	N	N	N	F	N	N	N	F	P
increase profit per vehicle	N	N	N	P	N	N	P	P	N	N	F	N	N	N	F	N
increase customer appeal	N	N	F	N	N	N	F	N	N	N	F	N	N	N	F	N
expand markets	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N
increase sales price	N	P	N	F	N	P	N	F	N	P	N	F	N	P	N	F
increase foreign earnings	N	F	N	F	N	F	P	F	N	F	P	F	N	F	P	F
lower production costs	N	N	N	F	N	N	N	F	N	N	F	N	N	N	F	N
increase high margin sales	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P
reduce operating costs	N	N	F	N	N	N	F	N	N	N	F	N	N	N	F	N
lower environmental impact	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N
lower purchase costs	N	N	F	N	N	N	F	N	N	N	F	N	N	N	F	N
keep labour costs low	N	F	N	F	N	F	N	F	F	N	F	N	F	N	F	N
improve economies of production	N	N	N	N	N	N	N	N	N	N	F	N	N	N	F	N
lower gas price	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
improve mileage	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N
offer rebates	P	N	P	N	P	N	P	N	P	N	P	N	P	N	P	N
lower loan interest rates	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
lower sales price	F	N	F	N	F	N	F	N	F	N	F	N	F	N	F	N
reduce raw materials costs	N	N	N	N	N	N	N	N	F	N	F	N	F	N	F	N
outsource units of production	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
gas price rises	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
lower Japanese interest rates	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
US gas price rises	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Japanese gas price rises	N	N	N	N	N	N	N	P	N	N	N	P	N	N	N	P
Yen rises	N	N	N	N	F	N	F	N	F	N	F	N	F	N	F	N
Japanese rates rise	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Quantitative approach: example

Goal/Event	Relationship	Goal/Event
increase sales volume	$\xrightarrow{0.6-S}$	increase Toyota sales
increase Toyota sales	$\xrightarrow{0.6-S}$	increase VW sales
increase VW sales	$\xrightarrow{0.6-S}$	increase sales volume
increase customer loyalty	$\xrightarrow{0.4+}$	increase sales volume
increase sales prices	$\xrightarrow{0.5-}$	increase customer loyalty
increase car quality	$\xrightarrow{0.8+}$	increase customer loyalty
improve car services	$\xrightarrow{0.7+}$	increase customer loyalty
lower environment impact	$\xrightarrow{0.4+}$	increase customer loyalty
increase sales prices	$\xrightarrow{0.3+}$	improve car services
keep labour costs low	$\xrightarrow{0.7-}$	increase car quality
improve economies of production	$\xrightarrow{0.8+}$	lower purchase costs
Yen rises	$\xrightarrow{0.8+}$	increase foreign earnings
lower Japanese interest rates	$\xrightarrow{0.4+}$	lower sales price
Japanese rates rises	$\xrightarrow{0.8-}$	lower Japanese interest rates
Japanese rates rises	$\xrightarrow{0.6+}$	Yen rises
Yen rises	$\xrightarrow{0.4-}$	Japanese gas price rises
Japanese gas price rises	$\xrightarrow{0.6+}$	gas price rises
US gas price rises	$\xrightarrow{0.6+}$	gas price rises
gas price rises	$\xrightarrow{0.8-}$	improve mileage

Quantitative approach: example

Goals/Events	Exp 1				Exp 2				Exp 3				Init
	Init		Fin		Init		Fin		Init		Fin		
	S	D	S	D	S	D	S	D	S	D	S	D	S
increase return on investment (GM)	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.4	0.0	0.0	0.9	0.0	0.0
increase sales volume	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
increase profit per vehicle	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.4	0.0	0.0	0.9	0.0	0.0
increase customer appeal	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0	0.0
expand markets	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3
increase sales price	0.0	0.5	0.0	0.8	0.0	0.5	0.0	0.8	0.0	0.5	0.0	0.8	0.0
increase foreign earnings	0.0	0.9	0.0	0.9	0.0	0.9	0.8	0.9	0.0	0.9	0.8	0.9	0.0
lower production costs	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.6	0.0	0.0
increase high margin sales	0.0	0.6	0.0	0.6	0.0	0.6	0.0	0.6	0.0	0.6	0.0	0.6	0.0
reduce operating costs	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0
lower environmental impact	0.9	0.0	0.9	0.0	0.9	0.0	0.9	0.0	0.9	0.0	0.9	0.0	0.9
lower purchase costs	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0
keep labour costs low	0.0	0.9	0.0	0.9	0.0	0.9	0.0	0.9	0.9	0.0	0.9	0.0	0.9
improve economies of production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
lower gas price	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
improve mileage	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8
offer rebates	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3
lower loan interest rates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lower sales price	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.0	0.8
reduce raw materials costs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.7	0.0	0.7
outsource units of production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
gas price rises	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
lower Japanese interest rates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
US gas price rises	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japanese gas price rises	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0
Yen rises	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0

Exercise

- Let’s try to model the 3 actors Customer, Bank and House-vendor when the customer want to buy a new house from the House-vendor and has to ask money to the Bank.