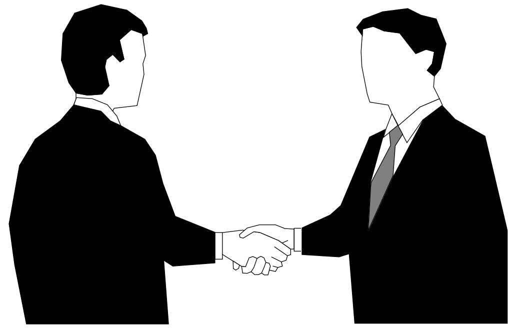
Thesis Presentation:



AN ANALYSIS OF SINGLE FUNCTION AGENTS AND THEIR NEGOTIATION BEHAVIOR IN EXPERT SYSTEMS

Bertram V. Dunskus
Computer Science Department, WPI

Advisor: Prof. David C. Brown
Reader: Prof. Lee A. Becker

July 12, 1994

Outline

1. Motivation
2. Definition of Single Function Agents (SiFAs)
3. Previous Work
4. SINE: A SiFA System with Negotiation
5. Evaluation
6. Conclusion
7. Future Research

Motivation

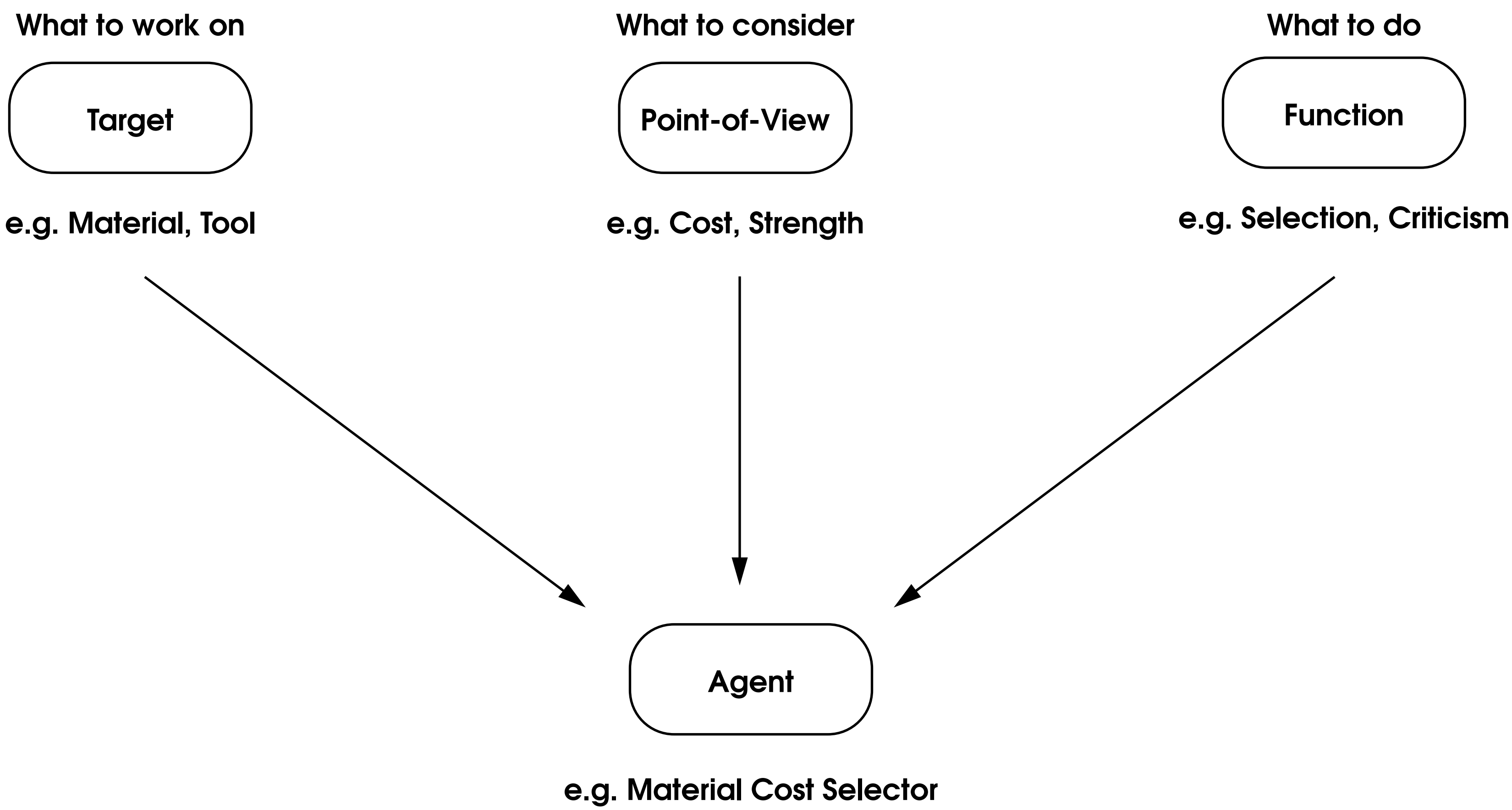
Practical Background

- Expert Systems needed for Concurrent Engineering (CE)
- This means inherently conflicting knowledge and interests
- Need to maintain expert knowledge without anticipating all possible conflicts
- Modular approach to AI Design System Developement
- Possibly mixture of human and machine agents
- Possibly agents located in different places

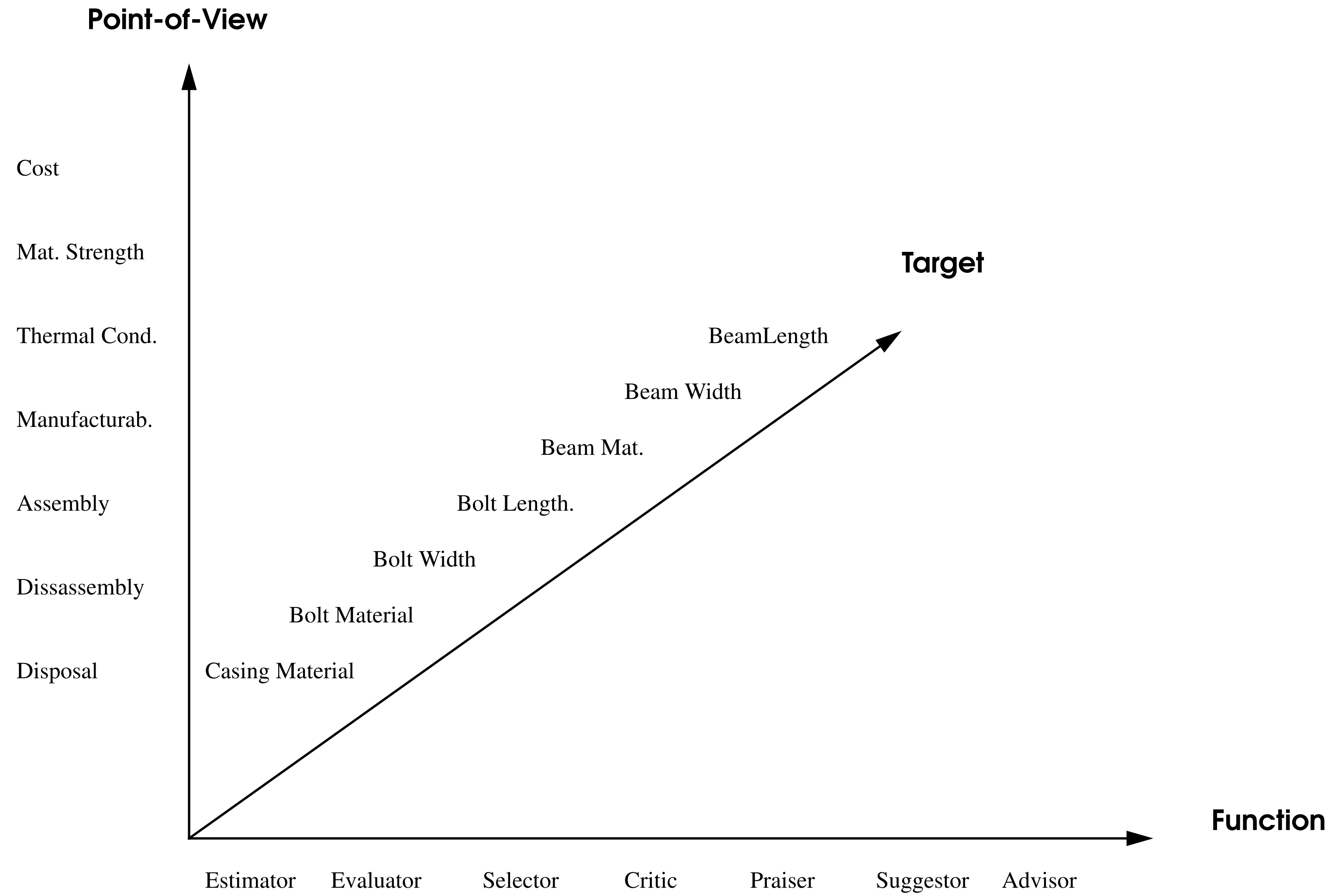
Theoretical Background

- Generic Tasks, design languages (e.g. DSPL)
- Distributed AI, agent based expert systems
- Conflict Resolution (CR) Theory (e.g. Klein)
- Object Oriented Approach

SiFA Definition



SiFA Matrix



Point-of-View
Cost
Mat. Strength
Thermal Cond.
Manufacturab.
Assembly
Dissassembly
Disposal
Target
BeamLength
Beam Width
Beam Mat.
Bolt Length.
Bolt Width
Bolt Material
Casing Material
Function
Estimator
Evaluator
Selector
Critic
Praiser
Suggestor
Advisor

SiFA Systems: Sneakers

- Goal: Train users about the importance and power of CE
- Single user system
- Team members simulated through expert system agents
- Domain: Tower Design

- Agents Functions: e.g. Estimators, Evaluator, Critics, Suggestors
- Points-of-View: e.g. Cost, Assembly, Disassembly, Marketing
- Targets: Tower (only one)

SiFA Systems: I3D/I3D+

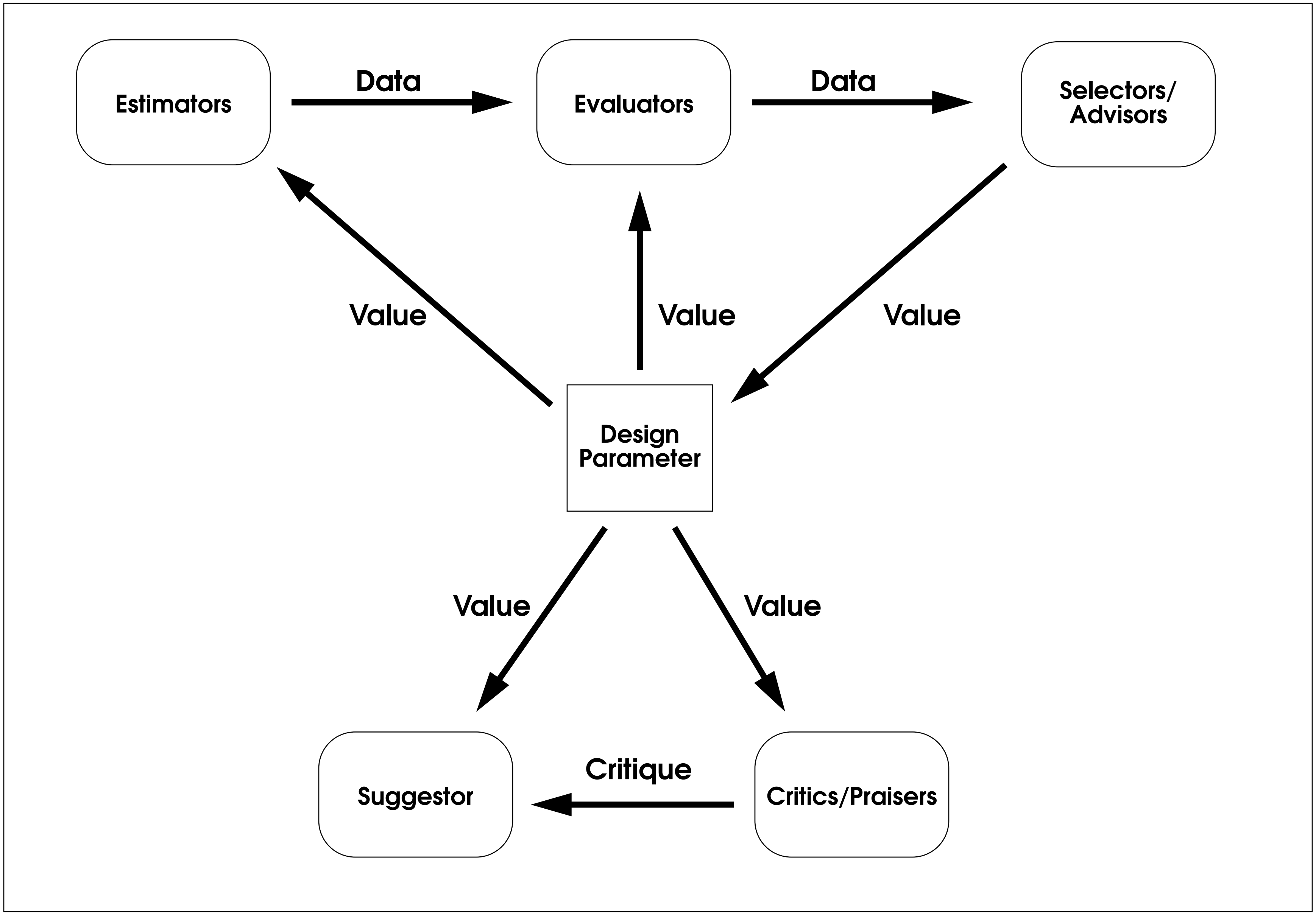
- Goal: Design simple powder ceramic components
- Single user
- Cooperative agents for conceptual and detailed design phases

- Agent Functions: estimation, selection, simulation, planning
- Points-of-View: Cost, Material Strength, Thermal Conductivity
- Targets: Material, Process, Inspection Mode

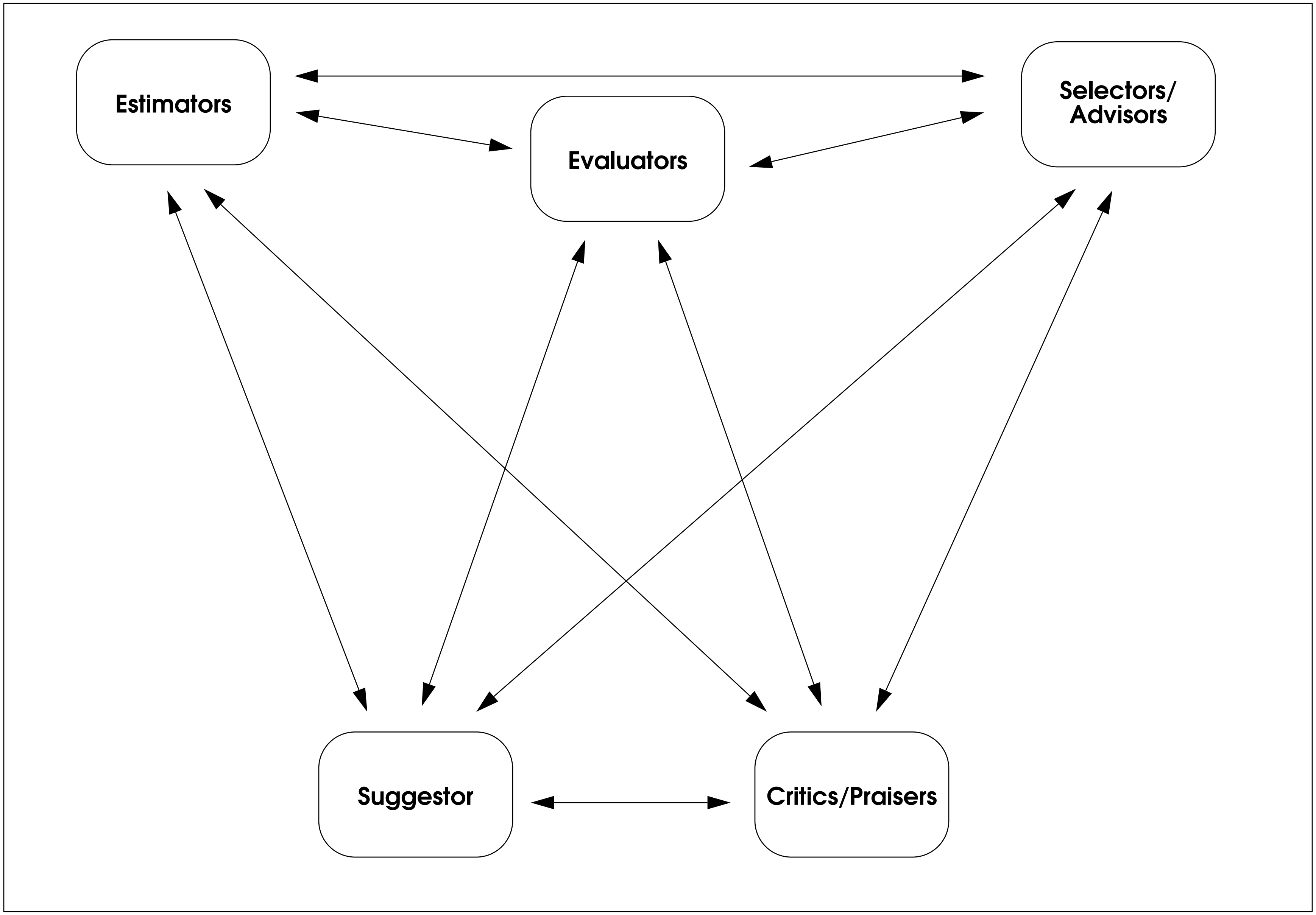
SINE: A SiFA System with Negotiation

- Goal 1: Build a reusable SiFA system for the future
- Goal 2: Implement domain-dependent and domain-independent CR
- Goal 3: Experiment with conflicts and their resolution in a CE system
- Goal 4: Design and implement a negotiation language for SiFAs
- No user interaction
- Cooperative but conflicting agents
- Agent functions: Selection, Estimation, Evaluation, Criticism, Praising, Suggestion
- Points-of-View: Bend-Strength, Thermal-Conductivity, Cost
- Targets: Material (only one)
- Domain: I3D Material Selection

Data Flow in SINE



Negotiation in SINE



Estimator

Design Parameters → f(p) → Derived Design Attributes

↑

Estimation Kn.

Role:

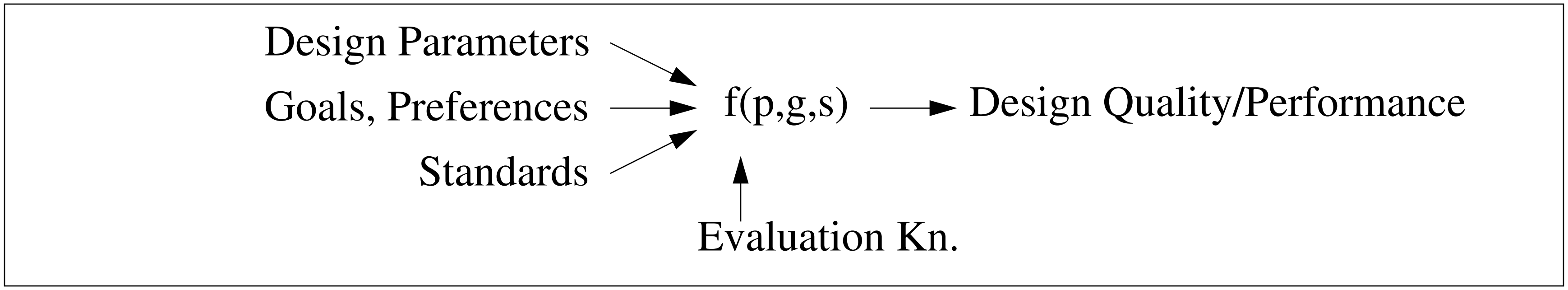
Produces approximate values derived from values of attributes of the design object. “Approximate”, because not necessarily all the values are available, or some of the values are already approximated or statistical, or the agent uses a function that is only close to, but not exactly, the function that applies in real life.

Conflicts:

- With Evaluator. Object: Not enough information available for Estimation. Cause: The evaluator’s output doesn’t provide the kinds of data that the estimator needs. Strategy: Try to come up with richer results from the evaluator.

- With Evaluator. Object: Estimator cannot come up with an accurate or reliable enough output, due to non-accurate output from the evaluator. Cause: The evaluator was using only a rough model or some of the information available, not all. Strategy: Switch to a more detailed model.

Evaluator



Role:

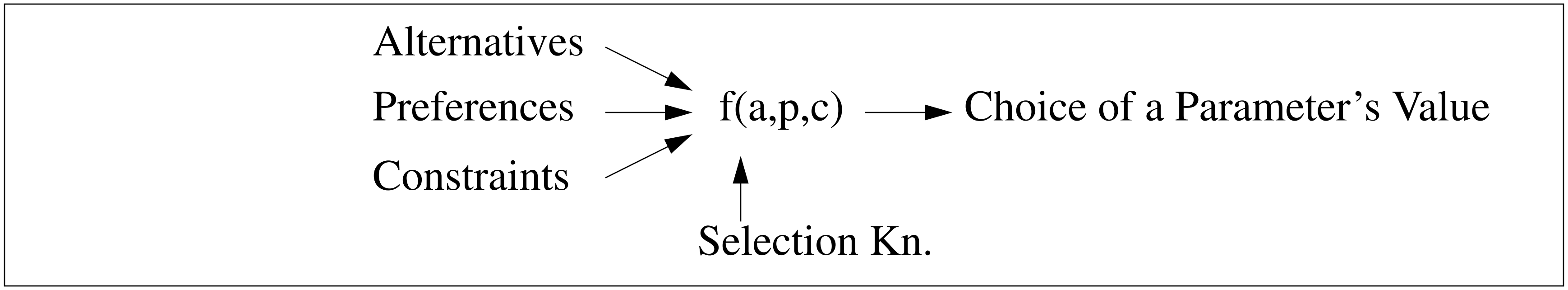
Uses design goals and attributes of the artifact to evaluate the design from one point of view. The result is an information about the quality of the design, i.e. how well the design meets the requirements or some explicit goal. The evaluation can be expressed numerically, e.g. in percent, or abstract, e.g. ‘good’, ‘average’ or ‘poor’. The evaluation does not make any statements about wether the achieved quality is satisfactory or not.

Conflicts:

- With Estimator. Object: Not enough information available for Evaluation. Cause: The estimator’s output doesn’t provide the kinds of data that the evaluator needs. Strategy: Try to come up with richer results from the estimator.

- With Estimator. Object: Evaluator cannot come up with an accurate or reliable enough output, due to non-accurate output from the estimator. Cause: The estimator was using only a rough model or some of the information available, not all. Strategy: Switch to a more detailed model.

Selector / Advisor



Role:

A Selector picks one item from a set of alternatives. In doing so, he can use a Preference, to rank alternatives, and constraints to filter only valid choices. Some possible items could be choice of a material from a list, suggested next steps, or some parameter for an attribute of the design object.

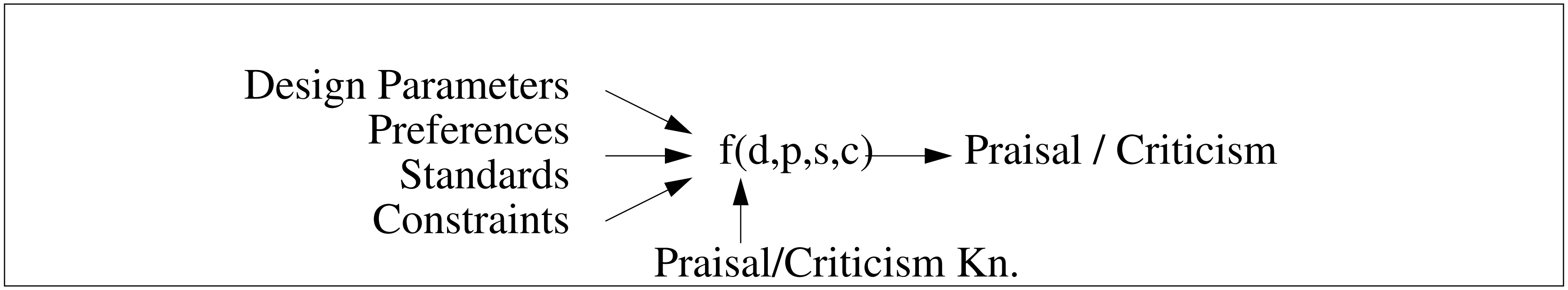
Conflicts:

- With another Selector. Object: Different Selection. Cause: Shallow Model (poor processing). Strategy: Abandon recommendations from the selector that uses the shallow model
- With another Selector. Object: Different Selection. Cause: Default Values, lack of information. Strategy: Replace invalid default values with real values and fill in knowledge gaps.
- With another Selector. Object: Different Selection. Cause: Differing Preferences. Strategy: Agree on common value, or convince other agent to abandon choice in favor of more important/global goals.
- With another Selector. Object: Different Selection. Cause: Different Constraints. Strategy: Build intersection of both agent's possible choices.
- With another Selector. Object: Differing Selection. Cause: Differing Knowledge of Alternatives. Strategy: Inform other agent of additional alternatives.

Selector / Advisor

- With Estimator/Evaluator. Object: Not enough information available for selection. Cause: Some criteria pertinent to the selection process are not available for that object. Strategy: Use more informed estimation or evaluation procedure, add needed criteria.
- With Estimator/Evaluator. Object: Alternatives don’t show enough difference in quality. Cause: Evaluation or estimation model is too weak to produce significantly different results for the input, maybe due to too high tolerances. Strategy: Improve estimation or evaluation contrast.
- With Estimator/Evaluator - Selector. Object: Not enough information available for estimation or evaluation. Cause: Some information to base the estimation or evaluation on is not available for the current choice. Strategy: Select an object which can be evaluated better, i.e. which has that information.

Critic / Praiser



Role:

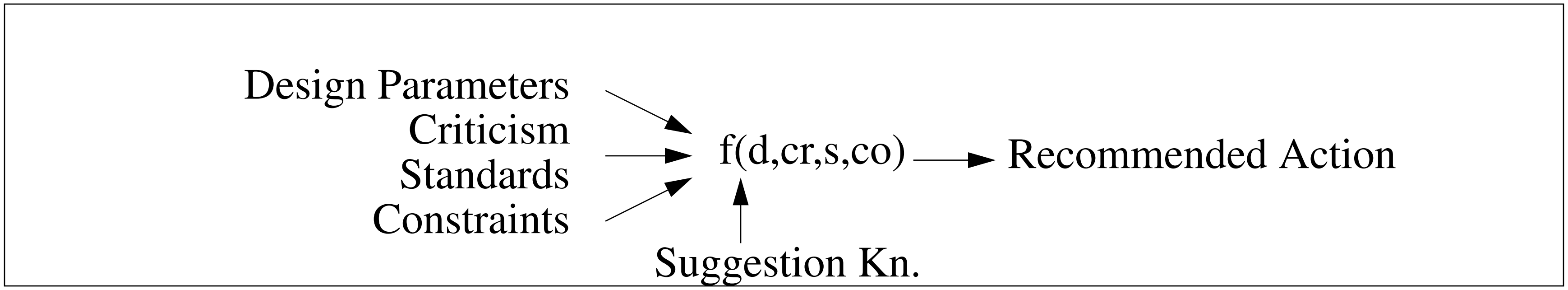
A Critic points out potential problems, suboptimal decisions, poor choices that stand in conflict with the preferences that are expressed in the requirements. Positive criticism is generated by “Praiser” agents.

Conflicts:

- With Estimator / Evaluator. Object: Not enough information gets used in estimation / evaluation. Cause: The critic wants to make sure that all the pertinent information is used. Strategy: Try to add additional design parameters, goals, preferences or standard into the estimation / evaluation data.
- With Estimator / Evaluator. Object: Poor processing model. Cause: Agents were only using a rough model to come up with a quick answer. Strategy: Switch to a more detailed model.
- With Estimator / Evaluator. Object: Not enough information available for Criticism. Cause: The estimator / evaluators output doesn’t provide the kinds of data that the critic needs. Strategy: Try to come up with richer results from the agents.

- With Selector: Unsatisfactory Selection. Cause: Constraint violated. Strategy: Inform Selector of constraint, try to select with the additional constraint.

Suggestor



Role:

The suggestor takes the criticism and the context and suggests alternative solutions for some previous design decisions.

Conflicts:

- With another Suggestor. Object: Different Suggestion. Cause: Shallow Model (poor processing). Strategy: Abandon recommendations from the Suggestor that uses the shallow model
- With another Suggestor Object: Different Suggestion. Cause: Default Values or lack of information. Strategy: Replace invalid default values with real values and fill in knowledge gaps.
- With another Suggestor. Object: Different Suggestion. Cause: Differing Local Optima (different evaluation methods and/or different goals). Strategy: Agree on common values, or convince other agent to abandon goal in favor of more important/global goals.

Suggestor (cont'd)

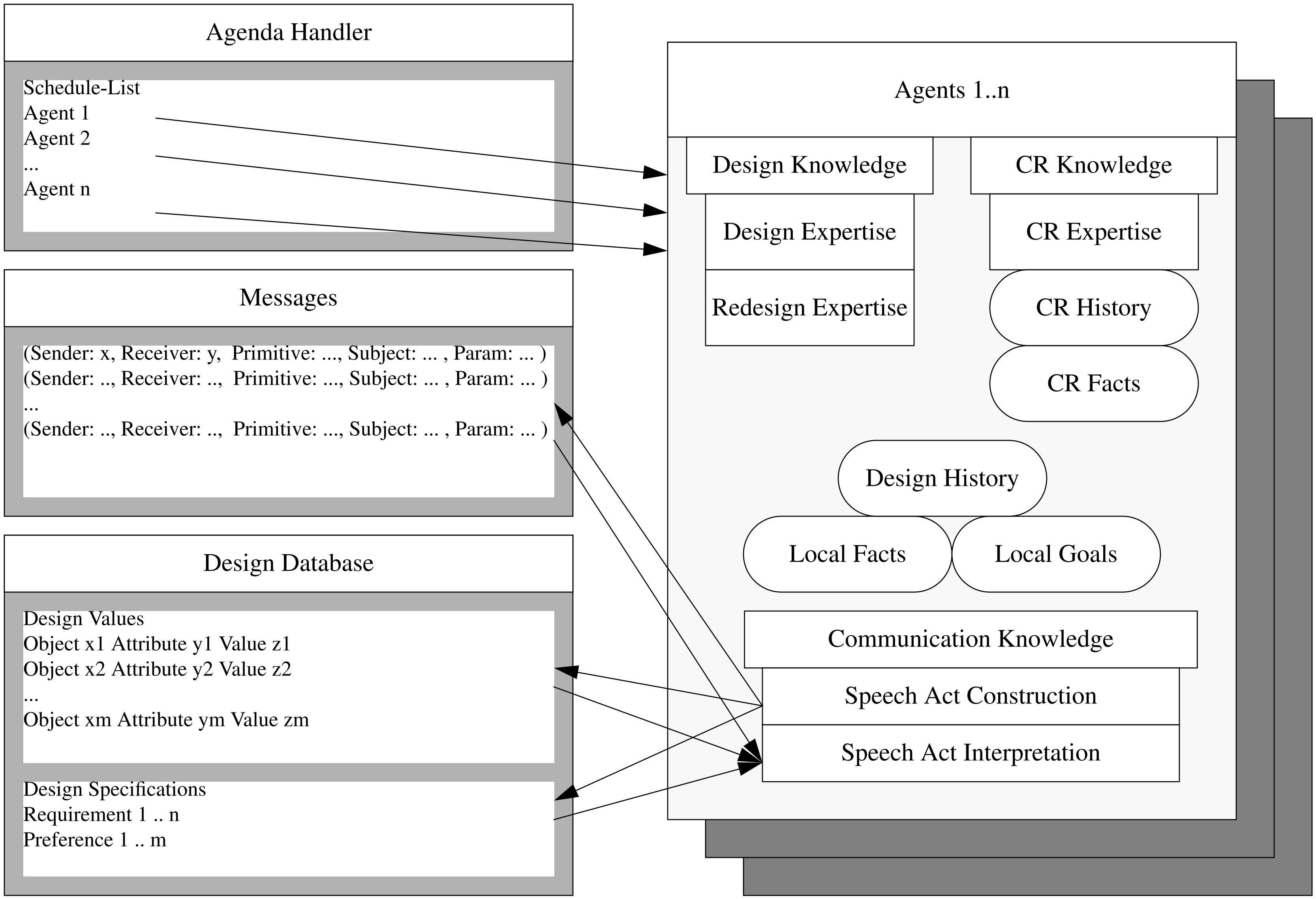
- With other agent types. Object: The suggestion cannot be implemented. Cause: The other agents do not know how to apply the suggestion to the situation. Strategy: Inquire possible alternatives from agent and operationalize suggestion accordingly.
- With other agent types. Object: The suggestion cannot be implemented. Cause: There are constraints that fail when other agents try to apply the suggestion. Strategy: Find a different plan that avoids the conflicts or modify plan to satisfy constraints.

SINE: Possible Negotiations

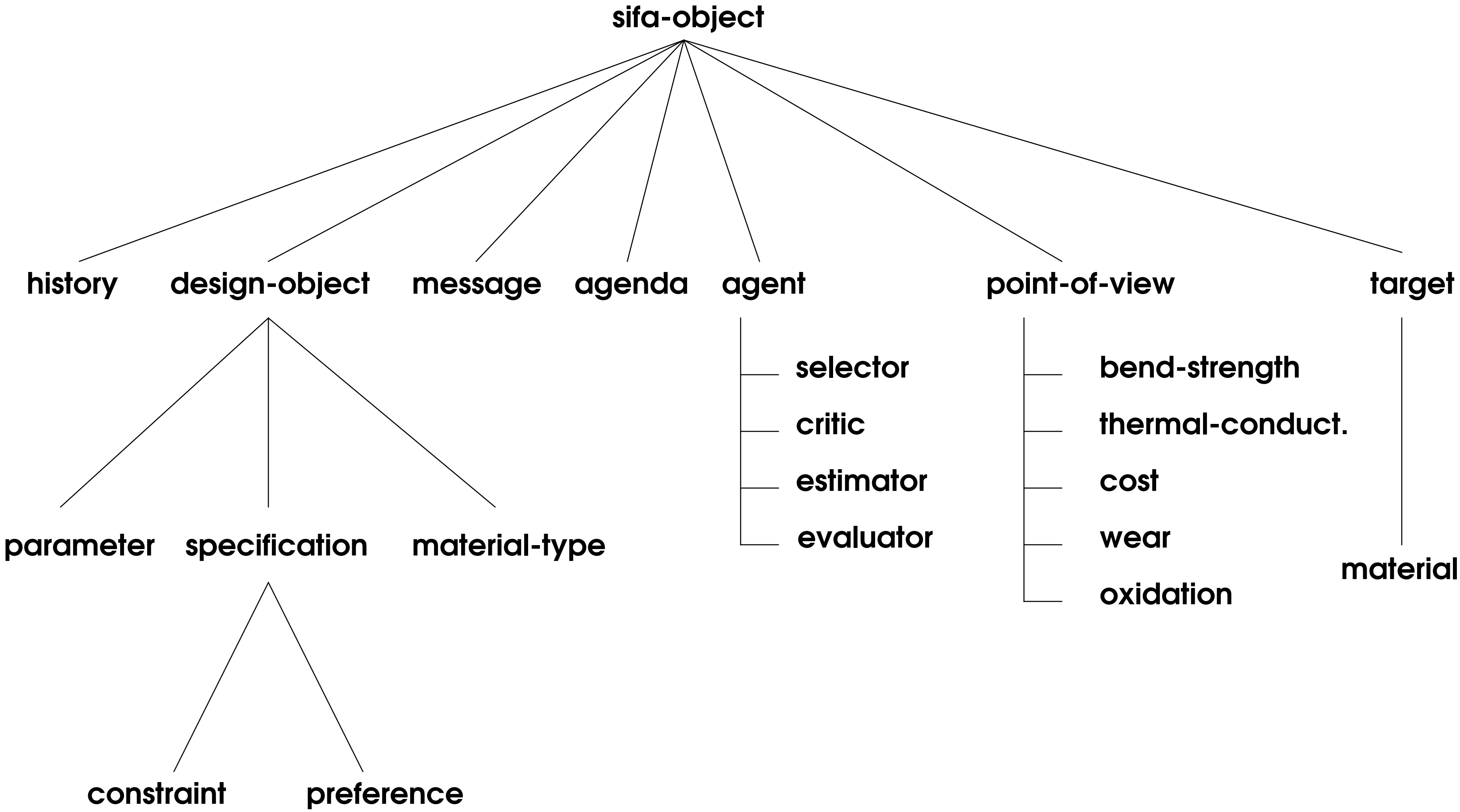
Table 1: Partners, Topics->Results

Initiators (below):	Estimator	Evaluator	Selector	Critic	Praiser	Suggestor
Estimator	Conflicting Estimations -> Modification of Estimation Basis		Poor Evaluation Basis -> Select different alternative, or give more details			
Evaluator	Incomplete Evaluation Basis -> Request to add Attributes	Conflicting Evaluations -> Modification of Evaluation Basis	Poor Evaluation Basis -> Select different alternative, or describe selection in more detail			
Selector	Poor Estimation Quality -> Request Modification of Estimate	Undercritical Evaluation -> Request Refinement of Evaluation	Constraint Failure, Preferences -> Removal and Reordering of Alternatives			No selection between several suggestions possible -> Refine Rationale
Critic	Complaint about Quality of Estimation -> Modify Estimation Procedure	Complaint about Quality of Evaluation -> Modify Evaluation Criteria	Disqualification of Alternatives -> Additional Constraints	Conflicting Criticism (e.g. too high and too low) -> Agreement on Cr.	Conflicting Statements -> Re-evaluate or retract	
Praiser			Approval of Choices -> Reordering of preferred Selection Method	Conflicting Statements -> Re-evaluate or retract	Conflicting Praisals -> Compromize	Unwanted Change Suggestion -> Receive Reason for Improvement
Suggestor	Improve Estimation -> Add/Remove Item Types, Methods	Improve Evaluation -> Add/Remove Attribute Types, Methods	Improve Selection Process -> Intensify Search; Extend Search Space	Enable Selection -> Relax Constraint	Reduce Selection -> Narrow Constraints	Conflicting Suggestion -> Agreement on common suggestion

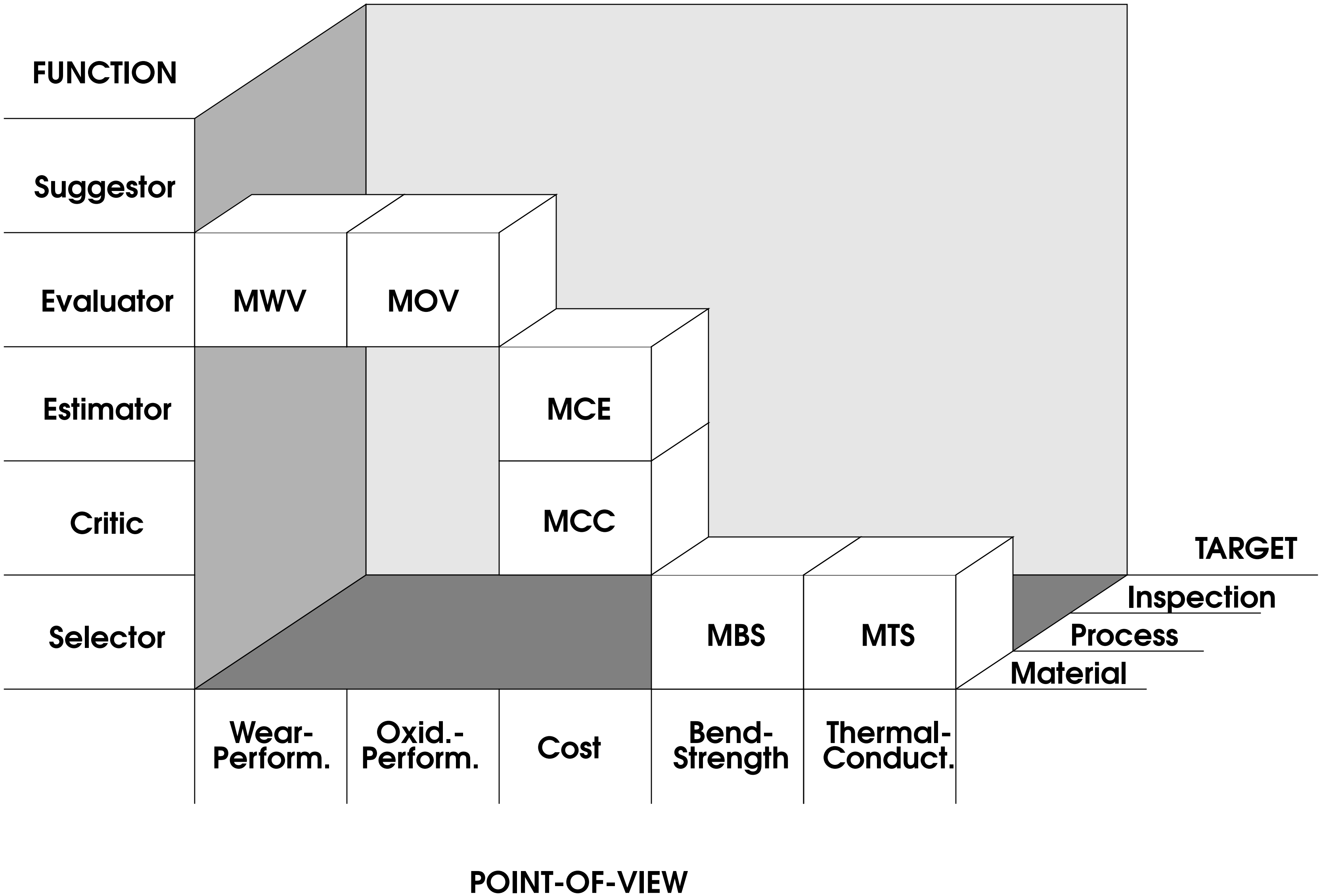
SINE: Architecture



SINE: Class Inheritance



SINE: Agent Inheritance



SINE: Implementation

- CLIPS Expert System Shell (Source code in C), developed by NASA
- Library of SiFA classes and methods developed for CLIPS
- CLIPS rules for design and CR
- C Functions for I/O handling

Speech Acts: Structure (modeled after KQML)

- primitive
- subject
- parameter1
- parameter2
- in-reply-to
- language
- ontology
- receiver
- reply-with
- sender
- timestamp

Example

• primitive	tell
• subject	proposal-count
• parameter1	1
• parameter2	
• in-reply-to	[msg14]
• language	sifa_language
• ontology	sifa_ontology
• receiver	[mts]
• reply-with	[msg15]
• sender	[mbs]
• timestamp	12

Speech Acts: Proposals and Alternatives

Proposals

"I agree with your proposal for design-value x."

tell	proposal	agree

"Can you come up with a different proposal?"

ask-if	proposal-count	1

"I have have x proposals."

tell	proposal-count	<value>

Alternatives

"Add the following alternative to your list of considered choices."

insert	alternative	<alternative-name>

"Remove the following alternative from your list of considered choices."

delete	alternative	<alternative-name>

Speech Acts: Constraints and Processes

Constraints

"What are your (all, satisfied or unsatisfied) constraints?"

ask-about	constraint	{all | <status>}	

"My constraint is/are"

tell	constraint	{<constraint-name> <status>}*	

"Add the constraint to your list of things to consider"

insert	constraint	<constraint-name>	

Processes

"What process are you using?"

ask-about	process	current	

"I use the following process: ...."

tell	process	<process-name>*	

"Please use the process x"

tell	request-process	<process-name>	

"I accept your request for process x"

tell	request-process	accept	<process-name>

SINE: Sample Trace

```
CLIPS>
(Design)
agenda: **** Schedule for Cycle 1 ****
agenda: Material Bend-Strength Selector because of usage, ranked at  60
agenda: Material Thermal-Conductivity Selector because of usage, ranked at  60
agenda: **** Executing Cycle 1 ****
agenda: Running Material Bend-Strength Selector because of usage
mbs: Starting cycle 1
mbs: Recommendations: ()
mbs: Forbiddens: ()
mbs: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mbs: Remaining: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mbs: Checking constraint: [bendstrength_con]
mbs: Looking for best choice in: ([SN0] [SN1] [SN2] [SN])
mbs: Selecting Silicon Nitride - No Wear Info [SN0] for Material Parameter
main: Initializing Material Parameter with Silicon Nitride - No Wear Info from Material Bend-Strength Selector
mbs: Material Bend-Strength Selector was able to select his preferred value for Material Parameter
mbs: Finished cycle 1
mbs:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 2 ****
agenda: Material Thermal-Conductivity Selector because of usage, ranked at  60
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 2 ****
agenda: Running Material Thermal-Conductivity Selector because of usage
mts: Starting cycle 2
mts: Recommendations: ()
mts: Forbiddens: ()
mts: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Looking for best choice in: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Selecting Silicon Carbide No-Wear [SC1] for Material Parameter
main: Material Thermal-Conductivity Selector cannot store Silicon Carbide No-Wear in Material Parameter,
because Material Bend-Strength Selector [MAIN::mts] had already stored Silicon Nitride - No Wear Info.
main: selection_selection conflict detected between Material Thermal-Conductivity Selector and Material Bend-
Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for number of proposals, replying with: 4
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Soliciting another proposal from Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for a different proposal, replying with: [SN1]
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Agreeing with alternate proposal [SN1] from agent Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Modifying design value to accept proposed change from agent Material Thermal-Conductivity Selector
main: Material Bend-Strength Selector overrides old value Silicon Nitride - No Wear Info in Material Parameter
with Silicon Nitride - No density info
mts: Finished cycle 2
mts:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 3 ****
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 3 ****
agenda: Running Material Cost Estimator because of usage
mce: Starting cycle 3
mce: The mass of the part made from Silicon Nitride - No density info is 0 kg.
mce: Constraint: Constraint for valid density failed.
mce: Constraint: Constraint for valid unit_cost satisfied.
main: selection_estimation conflict detected between Material Cost Estimator and Material Bend-Strength Selec-
tor
mce: Current material 'Silicon Nitride - No density info' violated the Constraint for valid density
mce: Requesting Material Bend-Strength Selector to insert the [density_con] to his list of constraints
main: Sending message from Material Cost Estimator to Material Bend-Strength Selector
mbs: Got told by Material Cost Estimator to insert constraint [density_con], into his list.
main: Adding Constraint for valid density to Material Bend-Strength Selector
mce: Finished cycle 3
mce:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 4 ****
agenda: Material Bend-Strength Selector because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 4 ****
agenda: Running Material Bend-Strength Selector because of usage
mbs: Starting cycle 4
mbs: Recommendations: ()
mbs: Forbiddens: ()
mbs: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mbs: Remaining: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mbs: Checking constraint: [density_con]
mbs: Remaining: ([SC0] [SC1] [SC2] [SC] [SN0] [SN2] [SN] [AL] [ZR])
mbs: Checking constraint: [bendstrength_con]
mbs: Looking for best choice in: ([SN0] [SN2] [SN])
mbs: Selecting Silicon Nitride - No Wear Info [SN0] for Material Parameter
main: Material Bend-Strength Selector overrides old value Silicon Nitride - No density info in Material Parameter
with Silicon Nitride - No Wear Info
mts: Current value Silicon Nitride - No Wear Info for target is different from preferred choice Silicon Nitride - No
density info, scheduling mts for conflict resolution.
mbs: Material Bend-Strength Selector was able to select his preferred value for Material Parameter
mbs: Finished cycle 4
mbs:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 5 ****
agenda: Material Thermal-Conductivity Selector because of conflict, ranked at  100
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 5 ****
agenda: Running Material Thermal-Conductivity Selector because of conflict
mts: Starting cycle 5
mts: Recommendations: ()
mts: Forbiddens: ()
mts: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Looking for best choice in: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Selecting Silicon Carbide No-Wear [SC1] for Material Parameter
main: Material Thermal-Conductivity Selector cannot store Silicon Carbide No-Wear in Material Parameter,
because Material Bend-Strength Selector [MAIN::mts] had already stored Silicon Nitride - No Wear Info.
main: selection_selection conflict detected between Material Thermal-Conductivity Selector and Material Bend-
Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for number of proposals, replying with: 3
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Soliciting another proposal from Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for a different proposal, replying with: [SN2]
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Agreeing with alternate proposal [SN2] from agent Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Modifying design value to accept proposed change from agent Material Thermal-Conductivity Selector
main: Material Bend-Strength Selector overrides old value Silicon Nitride - No Wear Info in Material Parameter
with Silicon Nitride - No unit cost
mts: Finished cycle 5
mts:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 6 ****
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 6 ****
agenda: Running Material Cost Estimator because of usage
mce: Starting cycle 6
mce: The mass of the part made from Silicon Nitride - No unit cost is 0.005 kg.
mce: The cost for the object made from Silicon Nitride - No unit cost is 0.0 $ per part.
mce: Constraint: Constraint for valid density satisfied.
mce: Constraint: Constraint for valid unit_cost failed.
main: selection_estimation conflict detected between Material Cost Estimator and Material Bend-Strength Selec-
tor
mce: Current material 'Silicon Nitride - No unit cost' violated the Constraint for valid unit_cost
mce: Requesting Material Bend-Strength Selector to insert the [unit_cost_con] to his list of constraints
main: Sending message from Material Cost Estimator to Material Bend-Strength Selector
mbs: Got told by Material Cost Estimator to insert constraint [unit_cost_con], into his list.
main: Adding Constraint for valid unit_cost to Material Bend-Strength Selector
mce: Finished cycle 6
mce:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 7 ****
agenda: Material Bend-Strength Selector because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 7 ****
agenda: Running Material Bend-Strength Selector because of usage
mbs: Starting cycle 7
mbs: Recommendations: ()
mbs: Forbiddens: ()
mbs: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mbs: Remaining: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN] [AL] [ZR] [ZR0])
mbs: Checking constraint: [unit_cost_con]
mbs: Remaining: ([SC1] [SC2] [SC] [SN0] [SN1] [SN] [AL] [ZR] [ZR0])
mbs: Checking constraint: [density_con]
mbs: Remaining: ([SC1] [SC2] [SC] [SN0] [SN] [AL] [ZR])
mbs: Checking constraint: [bendstrength_con]
mbs: Looking for best choice in: ([SN0] [SN])
mbs: Selecting Silicon Nitride - No Wear Info [SN0] for Material Parameter
main: Material Bend-Strength Selector overrides old value Silicon Nitride - No unit cost in Material Parameter
with Silicon Nitride - No Wear Info
mts: Current value Silicon Nitride - No Wear Info for target is different from preferred choice Silicon Nitride - No
unit cost, scheduling mts for conflict resolution.
mbs: Material Bend-Strength Selector was able to select his preferred value for Material Parameter
mbs: Finished cycle 7
mbs:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 8 ****
agenda: Material Thermal-Conductivity Selector because of conflict, ranked at  100
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 8 ****
agenda: Running Material Thermal-Conductivity Selector because of conflict
mts: Starting cycle 8
mts: Recommendations: ()
mts: Forbiddens: ()
mts: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Looking for best choice in: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Selecting Silicon Carbide No-Wear [SC1] for Material Parameter
main: Material Thermal-Conductivity Selector cannot store Silicon Carbide No-Wear in Material Parameter,
because Material Bend-Strength Selector [MAIN::mts] had already stored Silicon Nitride - No Wear Info.
main: selection_selection conflict detected between Material Thermal-Conductivity Selector and Material Bend-
Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for number of proposals, replying with: 2
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Soliciting another proposal from Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for a different proposal, replying with: [SN]
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Agreeing with alternate proposal [SN] from agent Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Modifying design value to accept proposed change from agent Material Thermal-Conductivity Selector
main: Material Bend-Strength Selector overrides old value Silicon Nitride - No Wear Info in Material Parameter
with Silicon Nitride
mts: Finished cycle 8
mts:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 9 ****
agenda: Material Cost Estimator because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 9 ****
agenda: Running Material Cost Estimator because of usage
mce: Starting cycle 9
mce: The mass of the part made from Silicon Nitride is 0.005 kg.
mce: The cost for the object made from Silicon Nitride is 0.01125 $ per part.
mce: The total material cost for Silicon Nitride is roughly $ 22.5 for a batch size of 2000.
mce: Constraint: Constraint for valid density satisfied.
mce: Constraint: Constraint for valid unit_cost satisfied.
mce: Finished cycle 9
mce:
Press <return> to continue, or 'q' <return> to quit.
agenda: **** Schedule for Cycle 10 ****
agenda: Material Cost Critic because of usage, ranked at  60
agenda: Material Wear-Performance Evaluator because of usage, ranked at  60
agenda: Material Oxidation-Performance Evaluator because of usage, ranked at  60
agenda: **** Executing Cycle 10 ****
agenda: Running Material Cost Critic because of usage
mcc: Starting cycle 10
```

Selection-Selection Conflict

mts: Starting cycle 2
mts: Recommendations: ()
mts: Forbiddens: ()
mts: Alts+Recs-Forb= ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Looking for best choice in: ([SC0] [SC1] [SC2] [SC] [SN0] [SN1] [SN2] [SN] [AL] [ZR] [ZR0])
mts: Selecting 'Silicon Carbide No-Wear' [SC1] for Material Parameter
main: Material Thermal-Conductivity Selector cannot store 'Silicon Carbide No-Wear' in Material Parameter, because Material Bend-Strength Selector [MAIN::mts] had already stored 'Silicon Carbide No-Cost'.
main: selection_selection conflict detected between Material Thermal-Conductivity Selector and Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for number of proposals, replying with: 4
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Soliciting another proposal from Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Got asked by Material Thermal-Conductivity Selector for a different proposal, replying with: [SC1]
main: Sending message from Material Bend-Strength Selector to Material Thermal-Conductivity Selector
mts: Agreeing with alternate proposal [SC1] from agent Material Bend-Strength Selector
main: Sending message from Material Thermal-Conductivity Selector to Material Bend-Strength Selector
mbs: Modifying design value to accept proposed change from agent Material Thermal-Conductivity Selector
main: Material Bend-Strength Selector overrides old value 'Silicon Carbide No-Cost' in Material Parameter with 'Silicon Carbide No-Wear'
mts: Finished cycle 2

Selector-Estimator Conflicts

mce: Starting cycle 3
mce: The mass of the part made from Silicon Nitride - No density info is 0 kg.
mce: Constraint for valid density failed.
mce: Constraint for valid unit_cost satisfied.
main: selection_estimation conflict detected between Material Cost Estimator and Material Bend-Strength Selector
mce: Current material ‘Silicon Nitride - No density info’ violated the Constraint for valid density
mce: Requesting Material Bend-Strength Selector to insert the [density_con] to his list of constraints
main: Sending message from Material Cost Estimator to Material Bend-Strength Selector
mbs: Got told by Material Cost Estimator to insert constraint [density_con], into his list.
main: Adding Constraint for valid density to Material Bend-Strength Selector
mce: Finished cycle 3

mce: Starting cycle 6
mce: The mass of the part made from Silicon Nitride - No unit cost is 0.005 kg.
mce: The cost for the object made from Silicon Nitride - No unit cost is 0.0 $ per part.
mce: Constraint for valid density satisfied.
mce: Constraint for valid unit_cost failed.
main: selection_estimation conflict detected between Material Cost Estimator and Material Bend-Strength Selector
mce: Current material ‘Silicon Nitride - No unit cost’ violated the Constraint for valid unit_cost
mce: Requesting Material Bend-Strength Selector to insert the [unit_cost_con] to his list of constraints
main: Sending message from Material Cost Estimator to Material Bend-Strength Selector
mbs: Got told by Material Cost Estimator to insert constraint [unit_cost_con], into his list.
main: Adding Constraint for valid unit_cost to Material Bend-Strength Selector
mce: Finished cycle 6

Estimator-Critic Conflict

mcc: Constraint on the Material Cost satisfied.
mcc: Requesting estimate process info from Material Cost Estimator
main: Sending message from Material Cost Critic to Material Cost Estimator
mce: Got asked by Material Cost Critic for a description of its current process. Replying with ‘rough’
main: Sending message from Material Cost Estimator to Material Cost Critic
main: estimate_criticism conflict detected between Material Cost Critic and Material Cost Estimator
mcc: Requesting Material Cost Estimator to use the detailed process.
main: Sending message from Material Cost Critic to Material Cost Estimator
mce: Got asked by Material Cost Critic to change its current process to detailed
mce: Changing process for Material Cost Estimator to detailed
main: Sending message from Material Cost Estimator to Material Cost Critic
mcc: Received acceptance from Material Cost Estimator to use the detailed process

Selector-Critic Conflict

mcc: Constraint on the Material Cost failed.
mcc: Requesting estimate process info from Material Cost Estimator
main: Sending message from Material Cost Critic to Material Cost Estimator
mce: Got asked by Material Cost Critic for a description of its current process. Replying with ‘detailed’
main: Sending message from Material Cost Estimator to Material Cost Critic
mcc: Estimate quality of Material Cost Estimator is acceptable.
main: selection_criticism conflict detected between Material Cost Critic and Material Bend-Strength Selector
mcc: Requesting Material Bend-Strength Selector not to use the [SN] alternative
main: Sending message from Material Cost Critic to Material Bend-Strength Selector
mbs: Got told by Material Cost Critic to delete alternative [SN], from his list.
mbs: Removing alternative Silicon Nitride from Material Bend-Strength Selector

Comparison to previous SiFA systems

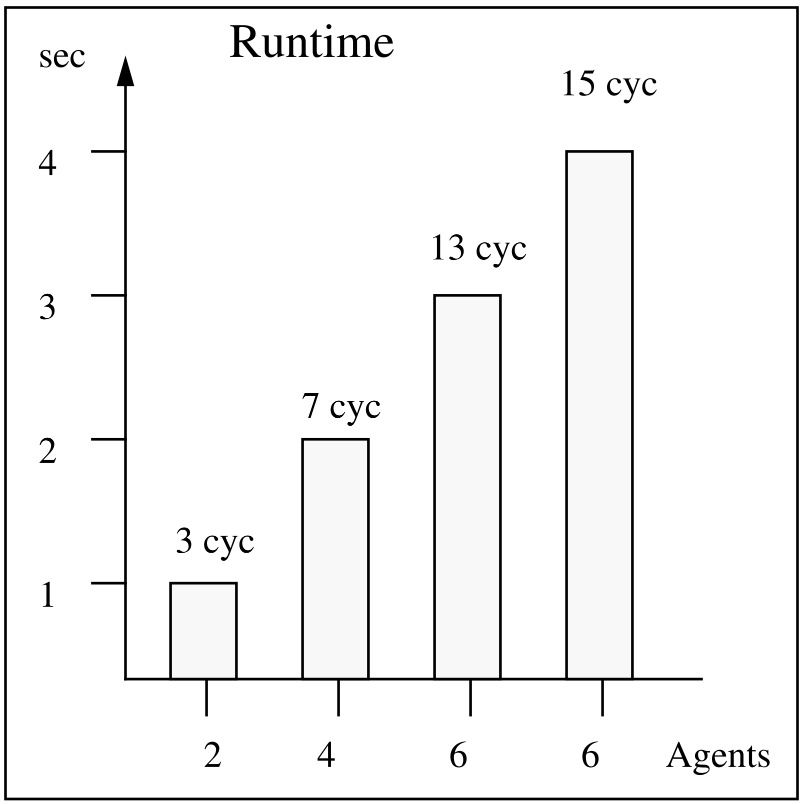
- SINE finds solutions for more combinations of requirements than I3D/I3D+
- Agents learn and reason about constraints, preferences and alternatives
- Support for constraint relaxation
- Easy development of design systems through agent templates and domain-independent functionality
- Use of knowledge databases to avoid data-representing rules

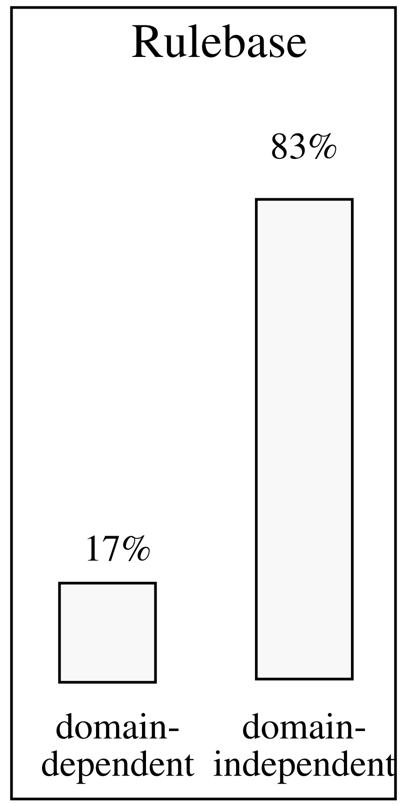
Understandability of Negotiation

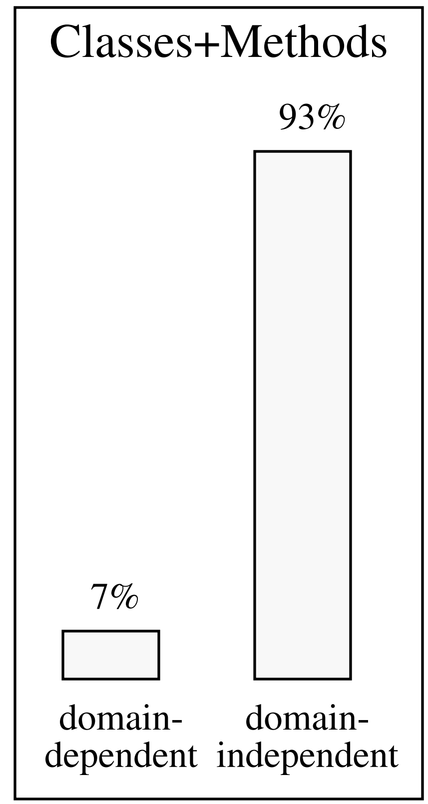
- System automatically generates human- and machine-readable output
- Explicit representation of constraints and preferences can make knowledge and communication understandable
- (more tests will be done)

Performance

- Runtime speedup through algorithmic parts and databases instead of large rule bases, especially for search operations with preferences.
- Uses modules instead of multiple CLIPS processes (faster)
- Development and maintenance are easier through external data files instead of rules







Comparison to Systems with larger Agents

- SINE makes building negotiating systems easier. SiFA Agents usually have a simple function and share something in common, e.g. function, target or point-of-view.

- Larger agents have more complex negotiation, as functionality is less restricted

- Large ratio of domain independent CR to domain-dependent CR, relative to systems with larger agents

- Design system development is easier, due to multiple inheritance and supporting functions

Conclusions

- Negotiation is useful in a design system
- Negotiation can be implemented
- A supporting software library is useful for development of SiFA systems

Future Research

- More Negotiation has to be implemented (between more agents and more variety withing the existing negotiation)
- Learning from Negotiation should be analyzed (Dan Grecu)
- SINE should be tried on a different domain (Sailboat design, Phil Tomlinson)
- A distributed implementation should be tried