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SEMANTIC CLASSIFICATION OF ACTIONS FOR KNOWLEDGE INFERENCE

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This paper proposes further development of Universal Semantic Code (USC). The notion of an action, represented by a verb, has been considered as a main component for knowledge inference. USC represents actions trough semantic strings and operates with semantic axioms to convert the strings to each other. That means the actions may be inferred from each other providing knowledge inference. In the example, semantic inference of actions applied to the text of the patent for revealing knowledge not included in the text and for reproducing full description of the inventive solution claimed in the patent.

Keywords: Universal Semantic Code, verb, action, axiom, knowledge inference, classifier, semantic string, natural language, representation

Introduction

In Natural Language Processing (NLP) numerous approaches of lexical classification exist, but classification of words and classification of meanings of the words are not the same. Regular dictionaries give a definition of meanings but not their classification. It excludes a possibility of knowledge inference (KI) from the sources.

Different linguistic approaches to a hypernym-hyponym classification have been developed. For example, the WordNet classification includes fifteen clusters for verbs and twenty-six for nouns comprising sets of synonyms (synsets) [Fellbaum, 1998]. It is certainly an achievement to define the WordNet classes, but contradiction and incompleteness of the approach does not allow using it for KI. The list of the verb clusters comprises ‘Contact verbs’ and ‘Creation verbs’, but not ‘Detach verbs’ and ‘Destruction verbs’. Non-functionality of some cluster names demonstrates inconsistence of the classification. So the cluster name ‘Weather verbs’ is not comparable with the name ‘Motion verbs’.

Another example is the Levin’s verb classification [Levin, 1993] which is more consistent because operates with opposite pairs of verb classes, for instance: ‘push/pull’. Unfortunately the approach of opposite pairs is incomplete; however it seems reasonable to build the verb classification using opposition as one of the building blocks.

Concerning the Levin’s classification M.Palmer wrote [Palmer et al., 1998]: “A primary task of lexical semantics is to find correct correspondences between the underlying semantic representation of the verb and its alternative syntactic realizations.” It would be reasonable to add the syntactic realization should be represented as a set of semantic strings for computer processing.

Traditional knowledge representation (KR) models like frames, semantic net, production rules, first order logic and others operate with formalisms apart of lexical classifications as internal component of the KR model [Harmelen et al., 2008].

The USC classification of actions represented by semantic strings covers the idea of combining NLP and KI in one tool [Martynov, 1992, 2001]. It may seem USC could be considered as a kind of the action language [Gelfond et al., 1998] but that is not true. There is only a terminological overlap in the word ‘action’.

Various authors have created a considerable scientific background in the field of NLP used for KI. For example, there are the conceptual dependence model by Schank [Schank, 1975], the model "sense <—> text" by Melchuk [Melchuk, 1974], the generative lexical theory by Pustejovsky [Pustejovsky, 1991], Amarel’s analysis about actions [Amarel, 1968]. Unfortunately their approaches do not provide formal representation paired with lexical base for semantic inference but provide strong basis, including philosophical and logical, for the evolution of semantic inference and inter alia for USC development.

1. USC Classes of Actions

USC postulates: knowledge can be kept by means of some internal semantic code and inference of the knowledge from the kept knowledge can be done on the basis of semantic axioms.

To implement any action USC defines four roles: X – subject, Y – instrument, Z – object, W – result. Such roles have shallow similarity with Fillmore's cases **[**Fillmore, 1968, 2003].

The USC classification proposes two types of actions: physical and informational. They are mutually correlated. Each class action defines a name of the class. Each action controlling a physical object is in the physical class and each action controlling an informational object is in the informational class.

So, the physical action (PA) "insert" assumes some physical object, which should be inserted. The informational action (IA) "memorize" assumes some informational object, which should be memorized. PA and IA classes are strictly correlated (Fig.1). A complete list of the classes is in the appendices 1 and 2.

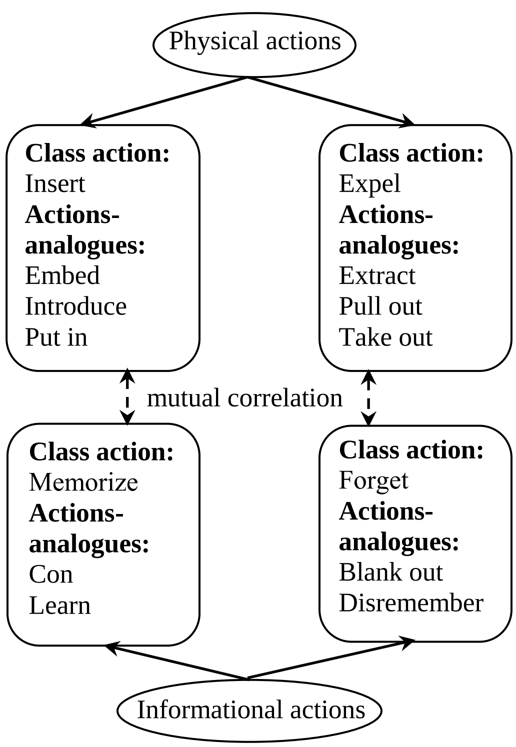

Fig.1. The USC classifier

Each class action has a corresponded list of actions-analogues and represented by the semantic string. Each string has a natural language interpretation defining roles of the action members.

The action 'insert' has a definition '*put or introduce into something'* and the USC interpretation "X by means of (bmo) Y inserts Z into W". We can define the members of the action and their roles. For example, for the initial phrase: "A nurse bmo a needle-syringe inserts a vitamin into the blood":

X - **nurse** is the subject
Y - **needle-syringe** is the instrument
Z - **vitamin** is the first object
W - **blood** is the second object

Each action-analogue of the class 'insert' has the same interpretation. So for the action "introduce", as a member of the class 'insert', the interpretation is: "X bmo Y introduces Z into W".

The action 'expel' has a definition *'draw or pull out, usually with some force or effort'* and the USC interpretation is: "X bmo Y expels Z from W":

X - **nurse** is the subject
Y - **needle-syringe** is the instrument
Z - **blood** is the first object
W - **vein** is the second object

The initial phrase is: "A nurse bmo a needle-syringe expels the blood from a vein".

Each action-analogue of the class "expel" has the same interpretation. So for the action "pull out", as a member of the class "expel", the interpretation is: "X bmo Y pulls Z out of W".

2. Formal Representation of Actions

In USC each action has two parts: **stimulus and reaction**. In physical world the USC notation ((X→Y)→Z) means stimulus with interpretation: X bmo Y affects on Z. In informational world the USC notation ((X→Y)→X) means stimulus with interpretation: X bmo Y affects on X (or on itself).

To define a reaction three conditions should be kept (Martynov, 2001):

1) The first element of the reaction is always a last element of the stimulus: (Z→…), because some action has happened with the object from the stimulus, for example, ((X→Y)→Z)→((Z→Z)→W) or shortly ((XY)Z)((ZZ)W).

An operation of implication [→] demonstrates the direction of the action. Each implication in the string is a directed influence of one variable on another or first part of the string on the second part.

2) Reaction may be 'active' or 'passive'. If reaction is 'active' the USC string in the second part is: ((XY)Z)**((ZZ)W)**. If reaction is 'passive' the USC string in the second part is: ((XY)Z)**(Z(ZW))**. It shows changing the position of the parenthesis in the right part of the string.

3) Spatial representation of members of the action.

In USC an operation [**'**] is a pointer to the position of one object with respect to another in space and considered as a complement of the location.

According to the USC spatial model, all existing objects can have one of three locations: to be in, to be on a surface, to be out of the surface. The notations: W, W', W'' mean accordingly 'inside', 'not inside' that is equal to 'superficially', and 'not superficially' that is equal to 'outside'.

For example, the actions: 'insert' is in, 'advance' is on, and 'target' is out. Such locations can be easy visualized (Fig.2).

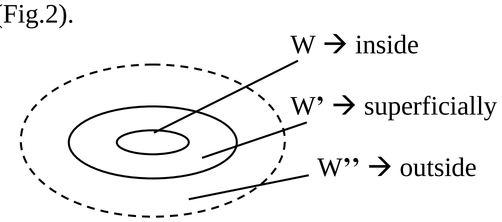

Fig.2 Location of the elements in the USC model

An experience of Talmy was used here. However, Talmy's basic objective is to identify certain 'conceptual structures' in language that are, in general, parallel to the structuring mechanisms in other cognitive domains such as visual perception [Talmy, 1988].

So far we have considered two opposite physical actions: "insert" and "expel".

Insert – **((XY)Z)((ZZ)W) –** "a nurse bmo a needle-syringe inserts a vitamin into the blood"

Expel – **((XY)Z)((ZW)Z)) –** "a nurse bmo a needle-syringe expels the blood from a vein"

Actions may be combined forming combined actions consisting of at least two actions; moreover the combined action can consist of two opposite actions.

For example, the combined action 'filter' consists of two opposite actions 'insert' and expel'. It would be wrong to consider negation "not filter" to the action 'filter' as an opposition. Generally, negation does not mean opposition.

The action 'filter' is represented by the string **(**(XY)Z)**[**((ZZ)W)((ZW)Z)**]** where the left part is the stimulus ((XY)Z) and the right part is the reaction combined from the left parts of the strings for 'insert' and 'expel' ((ZZ)W)((ZW)Z).

The interpretation of the string does not differ from the regular interpretations of the physical actions: X bmo Y filters Z of W.

3. USC Axioms

The axioms determine the rules of conversion of one USC string into another. Such conversion is knowledge inference or inference of a consequence of actions.

The consequence of actions cannot be arbitrary but explicitly inferred. Thus the phrase 'A child eats with his hands' will be axiomatically reconstructed as "A child eats with his **mouth, holding food with his** hands". It means the action 'hold' is the preceding action to the action 'eat'. Such reconstruction often is not important for a reader but is important for automatic semantic knowledge inference.

The formal part of the USC algebra has been determined as **< M, →, '** >, where **M** is a set of elements, **→** is a binary-non-commutative and non-associative operation on the given set (the operation of implication), [**'**] is an unary operation on the given set (the operation of complement).

3.1. Axiom of Transposition

The axiom defines shifting of internal parenthesis in the right part of the string:

((XY)Z)**((ZZ)W) →** ((XY)Z)**(Z(ZW))**

3.2. Axioms of Diffusion

The axiom defines transferring the variable from one position to another in the right part of the string.

a) Transferring the variable from the first position into the third: ((XY)Z)**((ZY)W) →** ((XY)Z)**((ZY)Z)**

b) Transferring the variable from the second position to the third: ((XY)Z)**((ZY)W) →** ((XY)Z)**((ZY)Y)**

c) Transferring the variable from the first position to the second: ((XY)Z)**((ZY)W) →** ((XY)Z)**((ZZ)W)**

3.3. Axiom of Permutation

The axiom defines simultaneous transferring the variable from the second position into the third and the variable from the third position into the second in the right part of the string: ((XY)Z)**((ZW)Y) →** ((XY)Z)**((ZY)W**

3.4. Axiom of Substitution

The axiom defines simultaneous substitution of the variables of the second and third positions, in the right part of the string, only if the second and third position variables are equal to each other but not equal to the variable in the firs position: ((XY)Z)**((ZW)W) →** ((XY)Z)**((ZY)Y)**

3.5. Axiom of Complement

The axiom defines converting one string into another, in the right part of the string, according to the spatial relation: ((XY)Z)**((ZZ)W)** → ((XY)Z)**((ZZ)W')** → ((XY)Z)**((ZZ)W")**

3.6. Axiom of Internal Relation

The axiom defines relation single and combined strings: ((XY)Z)**[((ZZ)W)((ZW)Z)]** → ((XY)Z)**((ZZ)W)**

4. Semantic Analysis for Engineering Solution

Every invention has been done to achieve some goal. This goal is stated in the invention description. The statement describes the goal function as one action or a set of actions, only one of which is final.

As a rule, a solution of the inventive problem is claimed as a patent for a method, device, or substance. The method is a sequence of the actions united to implement a technical process to achieve the goal. The device is a set of components assembled to implement the method.

Since, the method is a key concept, each action included in the method has semantics determining an order of its application. Only a strictly limited number of actions precedes the specified action and these actions are not arbitrary.

Since each action is located either before or after the certain action so, the action can be simultaneously of two types: preceding and consequent. The type of the action depends on a point of view: … → preceding action → current action → consequent action → …

The example demonstrates how a complete consequence of actions can be extracted from the patent descriptions.

To implement semantic inference of the inventive solution the lexical data base (LDB) was compiled and linked to the USC classifier. The LDB consists of four components:

- Relations between actions represented by verbs and deverbal nouns: 'move' as *moving, movement;* 'connect' as *connecting, connection.* (Leech, Rayson, and Wilson, 2001).
- Relations between actions and change of a parameter: 'cool' as *decrease temperature;* 'accelerate' as *increase speed*.
- Action-analogues according to the action class: Class '*insert';* action-analogues: *embed, enter, introduce, move into*
- Combined class actions: 'spray' as '*move+spread';* 'freeze on' as '*form+adjoin'*.

To show the example we take: the method of transportation of pulp through the conduit [patent 783154]. The goal of the invention is in reduction of abrasion of the conduit. The goal is achieved by the method of external cooling of walls of the conduit until forming on its internal surface a layer of frozen pulp.

Pulp is moving inside the conduit. An external refrigerant absorbs heat from the walls. The walls cool pulp inside of the conduit and freezing a protective layer on. This layer has the maximum thickness in the lower part of the conduit, which is the part mostly suffering from abrasion.

After freezing the layer of the calculated thickness the cooling device is turning off. The sensor, which signals about the level of abrasion of the protective layer from the frozen pulp, is installed on the conduit. When the layer is abraded to the defined value the cooling device repeatedly is turning on to produce additional freezing of the protective layer on.

The LDB relates the verb 'reduce' with the noun 'reduction'. It seams that the goal of the invention is determined by the action 'reduce'. Checking the USC classifier we find that the word 'reduce' is in the class 'change'. This class depends on the object of influence which in our case is a process of 'abrasion'.

In USC, a physical matter or parameter should be substituted in the position of the variable but not the name of the process. Therefore, the statement 'to reduce abrasion' is not correct since the concept 'abrasion' represents neither the physical object nor the physical parameter, but the process of abrasion. In the LDB, the noun 'abrasion' has a relation to the verb 'abrade' and we find the action 'abrade' as a member of the class 'damage' in the USC classifier.

We can conclude that a real goal of the invention is in saving the walls of the conduit from the undesirable process of abrasion and should be determined by the action 'save'. This conclusion is supported by the axiom of permutation. Checking the USC classifier the opposite action for 'abrade is 'save' and for the collocation 'reduce abrasion' the opposite action is 'save' as well.

Compiling together all actions, from the invention description, for achievement of the goal 'save' we receive the following sequence:

… → absorb → cool → freeze on → protect → save.

We can neglect with actions preceding the action 'absorb' because they are not the essential part of the invention and therefore not described in great details. Now we proceed mapping all important actions of the obtained sequence with the USC classifier and verify the members of the actions.

The action ‘absorb’ is in the PA class ‘insert’.
Absorb – ((XY)Z)((ZZ)W) – ‘X bmo Y inserts Z into W’
X – subject;
Y – refrigerant;
Z – heat;
W – refrigerant.

The value of the variable X is not specified because it is not important what kind of the device has been used. It is important that the device is using the refrigerant for cooling. Here, the refrigerant is absorbing heat that is why the values of the variables Y and W are the same.

The action ‘cool’ is in the PA class ‘expel’.
Expel – ((XY)Z)((ZZ)W) – ‘X bmo Y expels Z from W’
X – subject (device);
Y – refrigerant;
Z – heat;
W – pulp.

It is important to notice that expelling of heat from the object cools the object. That is why ‘cool’ semantically is an action-analogue for ‘expel’. The object of cooling is the pulp and is the value of the variable W.

According to the USC classifier, action ‘freeze on’ is a combined action consisting of two simultaneous actions ‘freeze’ and ‘adjoin’. The action ‘freeze’ is in the PA ‘form’ and the action ‘adjoin’ is the name of the class.
Freeze – ((XY)Z)(Z(WW)) – ‘X bmo Y forms W from Z’
Adjoin – ((XY)Z)((ZY)W’) – ‘X bmo Y adjoins Z to W’
Freeze on – ((XY)Z)[(Z(WW))((ZY)W’)] – ‘X bmo Y freezes Z on W’
X – subject;
Y – refrigerant;
Z – pulp layer;
W – internal surface of the conduit.

On that step we have to specify the values of the variables deeper then before. For instance, the variable Z has a value ‘pulp layer’, but not ‘pulp’, and the variable W has a value ‘internal surface of conduit’, but not ‘conduit’. It means we are moving from macro to micro level.

The action ‘protect’ is a name of the class.
Protect – ((XY)Z)((ZW)W”) – ‘X bmo Y protects Z from W’
X – refrigerant;
Y – frozen pulp layer;
Z – internal surface of conduit;
W – liquid pulp.

On this step the variable X has a particular value ‘refrigerant’ as a subject of the action. Implicitly, USC is leading to isolate the operational zone where the undesirable action occurs and the problem should be solved.

The action ‘save’ is a name of the class.
Save – ((XY)Z)(Z(WW”)) – ‘X bmo Y saves Z in W’
X – refrigerant;
Y – frozen pulp layer;
Z – internal surface of conduit;
W – conduit.

It is the final action of the whole process described in the invention. The variable X inherits the value ‘refrigerant’. The internal surface of the conduit is a part of the conduit and it is reasonable to define variables Z and W according to this relation.

Now we can write the solution of the problem in the form of the sequence of the right parts of the USC strings for the correspondent actions:
… → absorb → cool → freeze on (form+adjoin) → protect → save
… → (ZZ)W → (ZW)Z → (Z(WW))((ZY)W’) → (ZW)W” → Z(WW”)

We expect that the final string can be inferred as sequential converting one string into another according to the USC axioms:

1) According to the axiom of permutation:
(ZZ)W → (ZW)Z
2) No one axiom works for:
(ZW)Z → (Z(WW))((ZY)W’)
3) No one axiom works for:
(Z(WW))((ZY)W’) → (ZW)W”
4) According to the axiom of transposition:
(ZW)W” → Z(WW”)

Looking through axioms we can conclude that our axiomatic inference works partly or the given sequence of the USC strings is incomplete. In the case of incompleteness we are able to find out missing steps of the inference.

1) The axiom of permutation: (ZZ)W → (ZW)Z
2) The axiom of diffusion b): (ZW)Z → ***(ZW)W***
3) The axiom of transposition: ***(ZW)W*** → ***Z(WW)***
4) The axiom of internal relation:
Z(WW) → (Z(WW))((ZY)W’)
5) The axiom of internal relation:
(Z(WW))((ZY)W’) → ***(ZY)W’***
6) The axiom of diffusion c): ***(ZY)W’*** → ***(ZW)W’***
7) The axiom of complement: ***(ZW)W’*** → (ZW)W”
8) The axiom of transposition: (ZW)W” → Z(WW”)

Compiling the axiomatic sequence we receive:
… → (ZZ)W → (ZW)Z → ***(ZW)W*** → ***Z(WW)*** → (Z(WW))((ZY)W’) → ***(ZY)W’*** → ***(ZW)W’*** → (ZW)W” → Z(WW”)

After substitution of the strings with the corresponding actions of the USC classifier:
… → absorb → cool → ***produce*** → ***form*** → freeze on (form+adjoin) → ***adjoin*** → ***restore*** → protect → save

So, the complete process has been inferred. To finalize the analysis we consider interpretation of the inferred actions.

The action ‘produce’ is a name of the class.
Produce – ((XY)Z)((ZW)W) – ‘X bmo Y produces W from Z’

X – subject;
Y – refrigerant;
Z – liquid pulp;
W – frozen pulp.

The action ‘form’ is a name of the class.
Form – ((XY)Z)(Z(WW)) – ‘X bmo Y forms W from Z’

X – subject;
Y – refrigerant;
Z – frozen pulp;
W – layer of frozen pulp.

The action ‘adjoin’ is a name of the class.
Adjoin – ((XY)Z)((ZY)W’) – ‘X bmo Y adjoins Z and W’

X – subject;
Y – refrigerant;
Z – layer of frozen pulp;
W – internal surface of conduit.

The action ‘restore’ is a name of the class.
Restore – ((XY)Z)((ZW)W’) – ‘X bmo Y restores W from Z’

X – subject;
Y – refrigerant;
Z – abraded internal surface of conduit;
W – internal surface of conduit.

To simplify the final representation we can exclude from the axiomatic sequence the strings ***Z(WW)*** and ***(ZY)W’*** . Now the final sequence is:
… → (ZZ)W → (ZW)Z → ***(ZW)W*** → (Z(WW))((ZY)W’) → ***(ZW)W’*** → (ZW)W” → Z(WW”)
… → absorb → cool → ***produce*** → freeze on (form+ adjoin) → ***restore*** → protect → save

The example is demonstrating how implicit knowledge is becoming explicit. Of course, it is necessary to use human intervention for defining the values of the variables but inference of the consequence of the USC strings is automatic. For a natural language it can be compared with revealing ellipses in the sentence.

Conclusion

Initially, the approach was applied to infer only knowledge not included in the description of the inventive solution. But the approach can be applied for inventive problem solving. The inventive solution can be generated starting from the statement of the goal and moving back to each previous action for compiling a chain of the actions related through USC axioms [Boyko, 2001], [Kandelinski et al., 2014]. The number of possible solutions depends on the number of chosen axiomatic passes.

We would like to underline that USC unites several components including: definitions of the actions, its formal representation, natural language interpretation and axioms of inference. The latest version of the USC classifier has 108 classes: 54 physical and 54 informational classes. The whole set of actions comprises 5200 entities [Boyko, 2006]. Most of the combined actions comprise two components but there are few three and four component actions. For example, the action ‘cut off’ consists of three simultaneous class actions ‘touch+move+separate’.

Formal representation of actions as an intermediate code in “human-computer” interface is the essential property of USC. The USC strings have been used to represent not only actions, but also deverbal nouns and adjectives for development of the universal principles of text processing [Boyko, 2002].

However, we do not consider the USC model as a completed model. There are problems that should be developed, including: verification of combined actions, automatic substitution of members of the action, parallel inference of the consequences of the actions, evaluation of the quality of the inferred consequence.

Formal semantic coding for knowledge inference is a key component for KI. Majority of experiments in corpus-based natural language processing present results for some subtasks and there are few results that can be successfully integrated to build a complete NLP system with KI ability.

USC is the growing approach that can become a part of the class conceptual and computational framework forming the foundation of effective scalable natural language systems capable to knowledge inference.

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Appendix 1.

Classes of physical actions					
1.1	(ZY)W	**Connect** - make joined or united *X bmo Y connects Z and W*	2.1	(ZW)Y	**Disconnect** - make disconnected, disjoined *X bmo Y disconnects Z and W*
1.2	Z(YW)	**Fasten** - cause to be firmly attached *X bmo Y fastens Z and W*	2.2	Z(WY)	**Unfasten** - cause to be not firmly attached *X bmo Y unfastens Z and W*
1.3	(ZY)W’	**Adjoin** - make contact *X bmo Y adjoins Z and W*	2.3	(ZW)Y’	**Separate** - make a division or separation *X bmo Y separates Z and W*
1.4	Z(YW’)	**Touch** - be in direct physical contact with *X bmo Y touches Z and W*	2.4	Z(WY’)	**Detach** - come to be detached *X bmo Y detaches Z and W*
1.5	(ZY)W”	**Appose** - place in close proximity *X bmo Y apposes Z to W*	2.5	(ZW)Y”	**Distance** - place in far from each other *X bmo Y distances Z and W*
1.6	Z(YW”)	**Neighbor** - be located near *X bmo Y matches Z and W*	2.6	Z(WY”)	**Isolate** – set apart *X bmo Y isolates Z and W*
3.1	(ZZ)W	**Insert** - put or introduce into something *X bmo Y inserts Z into W*	4.1	(ZW)Z	**Expel** - force to leave or move out *X bmo Y expels Z from W*
3.2	Z(ZW)	**Fill** - occupy the whole *X bmo Y fills Z with W*	4.2	Z(WZ)	**Empty** - became empty or void of its content *X bmo Y empties Z of W*
3.3	(ZZ)W’	**Advance** - move forward *X bmo Y advances Z to W*	4.3	(ZW)Z’	**Remove** - remove from a close position *X bmo Y removes Z from W*
3.4	Z(ZW’)	**Approach** - move toward something *X bmo Y approaches Z to W*	4.4	Z(WZ’)	**Draw back** - pull back or move away *X bmo Y draws back Z from W*

3.5	(ZZ)W”	**Target** – intend to move towards a certain goal *X bmo Y targets Z to W*	4.5	(ZW)Z”	**Deflect** - turn from a straight course or fixed direction *X bmo Y deflects Z from W*
3.6	Z(ZW”)	**Line up** - place in a line or arrange so as to be parallel *X bmo Y lines up Z and W*	4.6	Z(WZ”)	**Angle** - move or proceed at an angle *X bmo Y angles Z and W*
5.1	(ZY)Z	**Contract** - squeeze or press together *X bmo Y contracts Z*	6.1	(ZZ)Y	**Expand** - make bigger or wider in size, volume, or quantity *X bmo Y expands Z*
5.2	Z(YZ)	**Compact** - make more compact *X bmo Y compacts Z*	6.2	Z(ZY)	**Widen** - become broader or wider *X bmo Y widens Z*
5.3	(ZY)Z’	**Concentrate** - draw together in one common center *X bmo Y concentrates Z*	6.3	(ZZ)Y’	**Spread** - distribute over an area *X bmo Y spreads Z*
5.4	Z(YZ’)	**Gather** - collect in one place *X bmo Y gathers Z*	6.4	Z(ZY’)	**Disperse** - move away from each other *X bmo Y disperses Z*
5.5	(ZY)Z”	**Hold** - keep in a certain state, position *X bmo Y holds Z*	6.5	(ZZ)Y”	**Release** - free from hold *X bmo Y releases Z*
5.6	Z(YZ”)	**Stay** - remain in a certain state *X bmo Y stays Z*	6.6	Z(ZY”)	**Leave** - go away from a place *X bmo Y leaves Z*
7.1	(ZY)Y	**Destroy** - damage irreparably *X bmo Y destroys Z*	8.1	(ZW)W	**Produce** - make by combining materials and parts *X bmo Y produces W from Z*
7.2	Z(YY)	**Deform** - make formless *X bmo Y deforms Z*	8.2	Z(WW)	**Form** - give shape or form *X bmo Y forms W from Z*
7.3	(ZY)Y’	**Break** - destroy the integrity *X bmo Y breaks Z*	8.3	(ZW)W’	**Restore** - return to its original or usable condition *X bmo Y restores W from Z*
7.4	Z(YY’)	**Fracture** – become fractured *X bmo Y fractures Z*	8.4	Z(WW’)	**Preserve** - keep or maintain in unaltered condition *X bmo Y preserves W in Z*
7.5	(ZY)Y”	**Attack** - begin to injure *X bmo Y attacks Z*	8.5	(ZW)W”	**Protect** - shield from danger, destruction, or damage *X bmo Y protects W from Z*
7.6	Z(YY”)	**Damage** - cause or do harm *X bmo Y damages Z*	8.6	Z(WW”)	**Save** - save from ruin, destruction, or harm *X bmo Y saves W in Z*
9.1	(ZZ)Z	**Change** - cause a physical transformation *X bmo Y changes Z*			
9.2	Z(ZZ)	**Transform** - change or alter in a form, appearance, or nature *X bmo Y transforms Z*			
9.3	(ZZ)Z’	**Move** - perform a motion *X bmo Y moves Z*			
9.4	Z(ZZ’)	**Displace** - put out of its place, position *X bmo Y displactes Z*			
9.5	(ZZ)Z”	**Handle** - cause to function *X bmo Y handles Z*			
9.6	Z(ZZ”)	**Operate** - perform as expected *X bmo Y operates Z*			

Appendix 2.

Classes of informational actions					
1.1	(XY)W	**Teach** - impart skills or knowledge *X bmo Y teaches Z*	2.1	(XW)Y	**Confuse** - make unclear or incomprehensible *X bmo Y confuses Z*
1.2	X(YW)	**Understand** - comprehend the nature or meaning *X bmo Y understands Z*	2.2	X(WY)	**Misunderstand** - interpret in the wrong way *X bmo Y misunderstands Z*
1.3	(XY)W’	**Inform** - impart knowledge of some fact *X bmo Y informs Z*	2.3	(XW)Y’	**Misinform** - give false or misleading information *X bmo Y misinforms Z*
1.4	X(YW’)	**Know** - be aware of information *X bmo Y knows Z*	2.4	X(WY’)	**Be unaware** - be unaware of information *X bmo Y is unaware of Z*
1.5	(XY)W”	**Disclose** - make known publicly *X bmo Y discloses W*	2.5	(XW)Y”	**Conceal** - prevent from being known *X bmo Y conceals W*
1.6	X(YW”)	**Follow** - keep informed *X bmo Y follows W*	2.6	X(WY”)	**Miss** - fail to reach or get *X bmo Y misses W*
3.1	(XX)W	**Memorize** - commit to memory *X memorizes W*	4.1	(XW)X	**Forget** - dismiss from the mind *X forgets W*
3.2	X(XW)	**Remember** - keep in mind *X remembers W*	4.2	X(WX)	**Discard** - throw or cast away *X discards W*
3.3	(XX)W’	**Associate** - make a logical or causal connection *X associates W*	4.3	(XW)X’	**Dissociate** - cease or break association *X dissociates W*
3.4	X(XW’)	**Deduce** - conclude by reasoning *X deduces W*	4.4	X(WX’)	**Speculate** - to believe on uncertain grounds *X speculates W*
3.5	(XX)W”	**Perceive** - to become aware of through the senses *X perceives W*	4.5	(XW)X”	**Lose -** fail to perceive with the senses or the mind *X loses W*
3.6	X(XW”)	**Consider** - take into consideration *X considers W*	4.6	X(WX”)	**Neglect** - give little or no attention *X neglects W*
5.1	(XY)X	**Encode** - convert information into code *X bmo Y encodes W*	6.1	(XX)Y	**Decode** - convert code into information *X bmo Y decodes W*
5.2	X(YX)	**Compress** - make more compact *X bmo Y compresses W*	6.2	X(XY)	**Decompress** - restore to its uncompressed form *X bmo Y decompresses W*
5.3	(XY)X’	**Summarize** - give a summary *X bmo Y summarizes W*	6.3	(XX)Y’	**Elaborate** - add details *X bmo Y details W*
5.4	X(YX’)	**Abstract -** consider a concept without thinking of a specific example *X bmo Y abstracts W*	6.4	X(XY’)	**Concretize** - become specific *X bmo Y concretizes W*
5.5	(XY)X”	**Focus** - bring into focus or alignment *X bmo Y focuses W*	6.5	(XX)Y”	**Distract** - draw attention away *X bmo Y distracts W*
5.6	X(YX”)	**Interest** - engage the interest *X bmo Y interests W*	6.6	X(XY”)	**Bore** - cause to be born *X bmo Y bores W*

7.1	(XY)Y	**Terminate** - bring to an end or halt *X terminates Y*	8.1	(XW)W	**Invent** - come up with an idea, explanation, theory *X bmo Y invents W*
7.2	X(YY)	**Expire** - lose validity *X expires Y*	8.2	X(WW)	**Innovate** - bring something new to an environment *X bmo Y innovates W*
7.3	(XY)Y'	**Disregard** - give little or no attention to *X disregards Y*	8.3	(XW)W'	**Research** - attempt to find out in a systematically manner *X bmo Y researches W*
7.4	X(YY')	**Err** - to make a mistake *X errs in Y*	8.4	X(WW')	**Solve** - find the solution to a problem or question) *X bmo Y solves W*
7.5	(XY)Y"	**Disorder** - bring disorder *X disorders Y*	8.5	(XW)W"	**Order** - bring order *X bmo Y orders W*
7.6	X(YY")	**Disorganize** - destroy systematic arrangement *X disorganizes Y*	8.6	X(WW")	**Systematize** - arrange according to a system *X bmo Y systematizes W*

9.1	(XX)X	**Think** - use the mind in order to make inferences, decisions *X thinks Y*
9.2	X(XX)	**Define** - give a definition for the meaning *X defines Y*
9.3	(XX)X'	**Calculate** - make a mathematical calculation or computation *X calculates Y*
9.4	X(XX')	**Determine** - establish after a calculation *X determines Y*
9.5	(XX)X"	**Evaluate** - place a value on *X evaluates Y*
9.6	X(XX")	**Compare** - examine and note the similarities or differences *X compares Y*