AN EXPERIMENTAL GRAMMAR FOR TRANSLATING ENGLISH TO JAPANESE

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TR-201 May 1982

ACKNOWLEDGEMENTS

I wish to express my gratitude to Dr. Robert F. Simmons for his valuable assistance with certain programs for this report and for his careful reading of this report, and to Dr. Frank M. Brown for worthwhile suggestions and comments.

I also wish to thank Hitachi Software Engineering Co. for giving me a chance to study Computer Sciences here in UT for two years.

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May, 1982

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1.Introduction

A computational approach for translating the sentences of one natural language to another has been reasonably well established by the basic method proposed by Satterthwaite [1965] and Tosh [1965]. The method is based on the following paradigm.

1. Transform the Input Language strings into a deep syntactic structure for that language

   IL ---> IL-DSS

2. Map from DSS in IL to a DSS for the Target Language

   IL-DSS ---> TL-DSS

3. Then generate the Target Language strings from DSS of the TL

   TL-DSS ---> TL

This report demonstrates the translation from English to Japanese by using the above paradigm where the deep syntactic

structure is sematic relations (SR). The semantic relations used here are linear expressions of a semantic network representation which describes a labelled dependancy structure of a sentence(Simmons and Chester [1980]. See the Example below). The report uses their grammar, which transforms English sentences into SRs of English, as the first step in translating English to Japanese. The other two steps are implemented by the rule system developed by the author and described here. The whole translation process is illustrated below.

First transform English sentences into SRs of English by using Simmons and Chester's English grammar

e.g. (THE GIANT ROCKET ROSE)

↓

(RISE AE (ROCKET DET THE SIZE (GIANT) NBR SING SNTRL SUB) TNS PAST)

AE Affected Entity, DET Determiner, SIZE, NBR Number, SING Singular, TNS Tense, SNTRL Sentence Relation, SUB Subject

Second, map from SR of English into SR of Japanese by using a system of translation rules

e.g.
(RISE AE (ROCKET DET THE SIZE (GIANT) NBR SING SNTRL SUB)
TNS PAST)

!
V

(AGARU AE (ROCKET POSTP WA SIZE (OHKII))
TNS PAST)

POSTP Postposition

Finally, generate Japanese sentences from the SR of Japanese by using a Japanese grammar

e.g.
(AGARU AE (ROCKET POSTP WA SIZE (OHKII))
TNS PAST)

!
V

(OHKII ROCKET WA AGATTA)

The following table shows a skech of translation.

ENG-SNT	--(English grammar)-->	SR (ENG)
		!
		! (Translation rules)
		V
JAP-SNT	<--(Japanese grammar)-	SR (JAP)

Table 1.1 Translation Scheme

Both the Japanese grammar and Translation rules developed here are written in HCPRVR language, a first order logic restricted to Horn Clauses, written in LISP by Chester [1980].

2.Semantic Relations in V-2 Rocket Story

This section describes how the grammar works and its results, the semantic relations of both the English and the Japanese sentences in the V-2 Rocket narrative. The V-2 Rocket story was the subject of psychological and linguistic studies by Beaugrande [1980], and the version used here has been the modified by Simmons and Chester. The Japanese version of the story was translated by the author.

The English text is given below.

> A great black and yellow V-2 rocket forty-six feet long stood in a NewMexico desert. Empty it weighed five tons. For fuel it carried eight tons of alcohol and liquid oxygen.
>
> Everything was ready. Scientists and generals withdrew to some distance and crouched behind earth mounds. Two red flares rose as a signal to fire the rocket.
>
> With a great roar and burst of flame the giant rocket rose slowly and then faster and faster. Behind it trailed sixty feet of yellow flame. Soon the flame looked like a yellow star.
>
> In a few seconds it was too high to be seen; radar tracked it as it sped upward to three-thousand mph. A few

minutes after it was fired the pilot of a watching plane saw it return. It plunged into earth forth miles from the starting point.

The Japanese translation of the text is given below.

46 feet no onkii kuroku kiiroi V-2 rocket wa NewMexico sabaku no naka ni tatteita. Kara de sore wa 5 ton no omosa ga atta. Nenryo ni sore wa 8 ton no alcohol to ekitai sanso o tsundeita.

Subete wa dekita. Kagakusha to shogun wa tohkuni hanarete, dote no ushiro ni suwatta. 2 hon no akai honoh ga rocket o uchiageru tame no aizu ni agatta.

Onkii oto to honoh to tomo ni, onkii rocket wa yukkuri soshite dandan hayaku agatta. Sore wa ushiro ni 60 feet no kiiroi honoh o niita. Suguni honoh wa kiiroi hoshi ni mieta.

Su byoh no nochi ni sore wa takasugite mienaku natta. Radar wa sore ga 3000 mph no hayasa made otta. Sore ga uchiagerarete kara su hun no nochi ni teisatsuki no pilot wa sore ga modoru tokoro o mita. Sore wa hassha chiten kara 40 mile no tokoro ni ochita.

The English grammar developed by Simmons and Chester produced the SRs of English listed in Table 2.1. The SRs of Japanese produced by the author's Japanese grammar.

The complete Japanese grammar for the sentences is presented in Appendix A. It is sectioned by Grammar rules and Lexical Assertions , which included wordclass, feature, arcname, etc. It has been debugged and runs in the HCPRVR LISP language.

```
1. (STAND AE (ROCKET DET A SIZE (GREAT)
                COLOR (BLACK *AND (YELLOW)) TYPE (V-2)
                LGTH (LONG LGTH (FOOT QU (FORTY-SIX) NBR PL))
                NBR SING SNTRL SUB)
           TNS PAST
           LOC (DESERT PREP IN DET A
                 LOC (NEWMEXICO) NBR SING))
2. (WEIGH AE (IT ST (EMPTY) NBR SING SNTRL SUB)
           TNS PAST
           MSR (TON QU (FIVE) NBR PL SNTRL OBJ))
3. (CARRY PU (FUEL PREP FOR NBR SING)
           AE (IT NBR SING SNTRL SUB)
           TNS PAST
           AE (ALCOHOL MSR (TON PREP OF QU (EIGHT) NBR PL)
                       NBR SING SNTRL OBJ
                  *AND (OXYGEN STATE (LIQUID) NBR SING)))
4. (BE AE (EVERYTHING NBR PL) TNS PAST ST (READY))
5. (WITHDRAW AGT (SCIENTIST NBR PL SNTRL SUB
                            *AND (GENERAL NBR PL)))
              TNS PAST
              LOC (DISTANCE PREP TO DET SOME NBR SING)
    *AND (CROUCH TNS PAST
         LOC (MOUND PREP BEHIND TYPE(EARTH NBR SING) NBR PL))
6. (RISE AE (FLARE QU (TWO) COLOR (RED) NBR PL SNTRL SUB)
          TNS PAST
          PU (SIGNAL PREP AS DET A
               PU (FIRE INF TO TNS PRES
                    AE (ROCKET DET THE NBR SING)) NBR SING))
7. (RISE AC (ROAR PREP WITH DET A SIZE (GREAT) NBR SING
             *AND(BURST SUBST(FLAME PREP OF NBR SING)NBR SING))
          AE (ROCKET DET THE SIZE (GIANT) NBR SING)
          TNS PAST
          RATE (SLOWLY *THEN (FASTER *AND FASTER)))
8. (TRAIL LOC BEHIND
           INSTR (IT NBR SING SNTRL SUB)
           TNS PAST
           SUBST (FLAME MSR (FOOT PREP OF QU (SIXTY) NBR PL)
                        COLOR (YELLOW) NBR SING SNTRL OBJ))
```

Table 2.1 Semantic Relations of Rocket story (English)

```
9. (LOOK TIME SOON
         AE (FLAME DET THE NBR SING SNTRL SUB)
         TNS PAST
         AP (STAR PREP LIKE DET A COLOR (YELLOW) NBR SING))
10. (BE TIME (SECOND PREP IN DET A QU (FEW) NBR PL)
        AE (IT NBR SING SNTRL SUB)
        TNS PAST
        HT (HIGH INTENS TOO
            RESULT (SEE INF TO AUX (BE TNS PRES) TNS PAST)))
11. (TRACK INSTR (RADAR NBR SING SNTRL SUB)
           TNS PAST
           AE (IT NBR SING SNTRL OBJ)
           DUR (SPEED AE (IT NBR SING SNTRL SUB)
                      TNS PAST
                      DIR UPWARD
                      RATE (MPH PREP TO
                                QU (THREE-THOUSAND) NBR PL)))
12. (SEE TIME (AFTER TIME (MINUTE DET A QU (FEW) NBR PL)
                          EVT (FIRE AE (IT NBR SING SNTRL SUB)
                                    AUX (BE TNS PAST) TNS PAST))
         AGT (PILOT DET THE *OF (PLANE PREP OF DET A
                                    INSTR* (WATCH TNS PRPRT)
                                    NBR SING SNTRL OBJ)
                        NBR SING SNTRL SUB)
         TNS PAST
         AE (RETURN AE (IT NBR SING SNTRL SUB) TNS PRES))
13. (PLUNGE INSTR (IT NBR SING SNTRL SUB)
           TNS PAST
           *TO (EARTH PREP INTO NBR SING)
           LOC (MILE QU (FORTY)
                      LOC (POINT PREP FROM DET THE
                                 LOC (START TNS PRES) NBR SING)
                      NBR PL))
```

Arcnames:
Affected Entity, DETerminer, SIZE, COLOR, TYPE, LenGTH, QUantity, NumBeR, TeNSe, LOCation, MeaSuRe, PURpose, weiGhT, PREPosition, *AND (conjunction), STATE, AGenT, INFinitive, ACCompany, SUBSTance, RATE, INSTRument,TIME, *THEN (temporal conjunction), HeighT, INTENSifier, DURation, RESULT, AUXiliary, DIRection, *OF(partof), SeNTenceReLation, INSTR* (back link through instrument), *TO (dirction to).

Table 2.1 Semantic Relations of Rocket Story(concluded)

```
1. (TATSU AE (ROCKET POSTP GA
                LGTH (NAGASA POSTP NO
                        MSR (FEET POSTP NO QU (*46 FORM ORG)))
                             QU (*46 FORM ORG)))
                SIZE (OHKII FORM ORG)
                COLOR (KUROI FORM CONT *AND(KIIROI FORM ORG))
                TYPE (V=2))
             LOC (NAKA POSTP NI
                      LOC (SABAKU POSTP NO LOC (NEWMEXICO)))
             AUX (IRU TNS PAST) TNS PAST)

2. (ARU AE (SORE POSTP WA) ST (KARA POSTP DE)
        WGT (OMOSA POSTP GA
                   MSR (TON POSTP NO QU (*5 FORM ORG)))
        TNS PAST)

3. (TSUMU AE (SORE POSTP WA) PU (NENRYO POSTP NI)
          AE (ALCOHOL POSTP O *AND(SANSO ST (EKITAI))
                MSR (TON POSTP NO QU (*8 FORM ORG)))
          AUX (IRU TNS PAST) TNS PAST)

4. (DEKIRU AE (SUBETE POSTP GA) TNS PAST)

5. (HANARERU AGT (KAGAKUSHA POSTP WA *AND (SHOGUN))
             LOC (TOHKUNI)
   *AND (SUWARU LOC (USHIRO POSTP NI LOC (DOTE POSTP NO))
                TNS PAST)
             FORM CONT TNS PAST)

6. (AGARU AE (HONOH POSTP GA
                   MSR (HON POSTP NO QU (*2 FORM ORG))
                   COLOR (AKAI FORM ORG))
          PU (AIZU POSTP NI
                PU (UCHIAGERU POSTP NO POSTP TAME
                   AE (ROCKET POSTP O) TNS PRES))
          TNS PAST)

7. (AGARU AE (TOMO POSTP NI
             *AND (OTO SIZE (OHKII FORM ORG) *AND (HONOH)))
          AE (ROCKET POSTP WA SIZE (OHKII FORM ORG))
          RATE (YUKKURI *AND (HAYAKU RATE (DANDAN)))
          TNS PAST)
```

Table 2.2 Semantic Relations of Rocket Story (Japanese)

```
8. (HIKU INSTR (SORE POSTP WA)
         LOC (USHIRO POSTP NI)
         AE (HONOH POSTP O
                  MSR (FEET POSTP NO QU (*60 FORM ORG))
                  COLOR (KIIROI FORM ORG))
         TNS PAST)

9. (MIERU TIME (SUGUNI)
          AE (HONOH POSTP WA)
          AP (HOSHI POSTP NI COLOR (KIIROI FORM ORG))
          TNS PAST)

10. (NARU TIME (NOCHI POSTP NI
                   TIME (BYOH POSTP NO QU (SU FORM ORG)))
          AE (ROCKET POSTP WA)
          HT (TAKAI INTENS (SUGITE) FORM ORG)
          AP (MIERU FORM CONT MOD NEG TNS PRES)
          TNS PAST)

11. (OIKAKERU INSTR (RADAR POSTP WA)
               DUR (TASSURU POSTP MADE
                 AE (ROCKET POSTP GA)
                 SP (HAYASA POSTP NI
                       MSR (MPH POSTP NO QU(*3000 FORM ORG))))
                                  QU (*3000 FORM ORG))))
               TNS PAST)

12. (MIRU TIME (NOCHI POSTP NI
             TIME (RUN POSTP NO QU (SU FORM ORG))
             EVT (UCHIAGERU POSTP KARA AE (ROCKET POSTP GA)
                   AUX (RARERU TNS PRES) TNS PRES))
          AGT (PILOT POSTP WA OF* (TEISATSUKI POSTP NO))
          AE (TOKORO POSTP O
               EVT (MODORU AE (SORE POSTP GA) TNS PRES)
          TNS PAST)

13. (OCHIRU INSTR (SORE POSTP WA)
            LOC (TOKORO POSTP NI
                  MSR (MILE POSTP NO
                       LOC (CHITEN POSTP KARA TYPE (HASSHA))
                                   TYPE (HASSHA))
             TNS PAST)
```

Table 2.2 Semantic Relations of Rocket Story(concluded)

Corresponding SRs of each language reveal some similarities of the structure. We make use of the similarities to translate. Before translating SRs of English in the next section we will look at the symmetry of the Japanese grammar from recordings of a console session testing the grammar on sentences of the rocket story text. First we set a variable to the sentence to be analyzed, then we call the function TRY, which applies the Japanese grammar to that sentence. Then we pretty-print the output, ask for the time it takes, then reset the arguments of the variable to show that the same grammar generates the original sentence from the output SRs. Comments are inserted in the form <<....>>.

```
==========================================================
*(sprint st1)
  << ST1 contains a sentence to be parsed.>>
(S12 (*46 FEET NO NAGASA NO OHKII KUROKU KIIROI V-2 ROCKET
          GA NEWMEXICO SABAKU NO NAKA NI TATTEITA)
     X
     X1)
NIL
*(try st1)
  << we call TRY to parse ST1. The CONTINUE question tell us
     that 100 subquestions have been asked; if we repond no,
     the proof will be abandaned.>>

CONTINUE? *y

((S12 (*46 FEET NO NAGASA NO OHKII KUROKU KIIROI V-2 ROCKET
GA NEWMEXICO SABAKU NO NAKA NI TATTEITA) (TATSU AE (ROCKET P
OSTP GA LGTH (NAGASA POSTP NO MSR (FEET POSTP NO QU (*46 FOR
M ORG))) SIZE (OHKII FORM ORG) COLOR (KUROI FORM CONT *AND (
KIIROI FORM ORG)) TYPE (V-2)) LOC (NAKA POSTP NI LOC (SABAKU
 POSTP NO LOC (NEWMEXICO))) AUX (IRU TNS PAST) TNS PAST) NIL
```

```
))

*rtime
(0.77300000 SECS)
  << It took real CPU time 0.773 secs in UCI LISP, HCPRVR
     DEC 2060 KI10.>>

*(sprint (car val))
  << Now we can look at the answer pretty-printed. VAL con-
     tains the answer.>>
(S12 (*46 FEET NO NAGASA NO OHKII KUROKU KIIROI V-2 ROCKET
          GA NEWMEXICO SABAKU NO NAKA NI TATTEITA)
     (TATSU AE
             (ROCKET POSTP
                     GA
                     LGTH
                     (NAGASA POSTP
                             NO
                             MSR
                             (FEET POSTP
                                   NO
                                   QU
                                   (*46 FORM ORG)))
                     SIZE
                     (OHKII FORM ORG)
                     COLOR
                     (KUROI FORM CONT *AND (KIIROI FORM ORG))
                     TYPE
                     (V-2))
             LOC
             (NAKA POSTP
                   NI
                   LOC
                   (SABAKU POSTP NO LOC (NEWMEXICO)))
             AUX
             (IRU TNS PAST)
             TNS
             PAST)
     NIL)
NIL
  << Now we set J to (s12 x semantic-relation nil) by using
     VAL.>>
*(setq j (car (subst x (cadar val) val)))
(S12 _X (TATSU AE (ROCKET POSTP GA LGTH (NAGASA POSTP NO MSR
 (FEET POSTP NO QU (*46 FORM ORG))) SIZE (OHKII FORM ORG) CO
LOR (KUROI FORM CONT *AND (KIIROI FORM ORG)) TYPE (V-2)) LOC
```

```
 (NAKA POSTP NI LOC (SABAKU POSTP NO LOC (NEWMEXICO))) AUX (
IRU TNS PAST) TNS PAST) NIL)

*(try j)
  << we will TRY to generate the original sentence.>>
((S12 (*46 FEET NO NAGASA NO OHKII KUROKU KIIROI V-2 ROCKET
GA NEWMEXICO SABAKU NO NAKA NI TAITEITA) (TATSU AE (ROCKET P
OSTP GA LGTH (NAGASA POSTP NO MSR (FEET POSTP NO QU (*46 FOR
M ORG))) SIZE (OHKII FORM ORG) COLOR (KUROI FORM CONT *AND (
KIIROI FORM ORG)) TYPE (V-2)) LOC (NAKA POSTP NI LOC (SABAKU
 POSTP NO LOC (NEWMEXICO))) AUX (IRU TNS PAST) TNS PAST) NIL
))
  << It generated the original sentence, showing the
     symmetry of the grammar.>>
*rtime
(0.60000000 SECS)

*(sprint st3)
(S13 (SORE WA NENRYO NI *8 TON NO ALCOHOL TO EKITAI SANSO O
          TSUNDEITA)
     X
     X1)
NIL
  <<we TRY ST3 to parse.>>
*(sprint (car (try st3)))

CONTINUE? *y
CONTINUE? *y

(S13 (SORE WA NENRYO NI *8 TON NO ALCOHOL TO EKITAI SANSO O
          TSUNDEITA)
     (TSUMU AE
            (SORE POSTP WA)
            PU
            (NENRYO POSTP NI)
            AE
            (ALCOHOL POSTP
                     O
                     *AND
                     (SANSO ST (EKITAI))
                     MSR
                     (TON POSTP NO QU (*8 FORM ORG)))
            AUX
            (IRU TNS PAST)
            TNS
            PAST)
```

```
     NIL)
NIL
*rtime
(1.9490000 SECS)

  << We also try to retrieve the original sentence by sub-
     stituting the variable x for the sentence but leaving
     its analysis as the second argument.>>
*(setq j (car (subst x (cadar val) val)))
(S13 _X (TSUMU AE (SORE POSTP WA) PU (NENRYO POSTP NI) AE (A
LCOHOL POSTP O *AND (SANSO ST (EKITAI)) MSR (TON POSTP NO QU
 (*8 FORM ORG))) AUX (IRU TNS PAST) TNS PAST) NIL)

*(try j)
((S13 (SORE WA NENRYO NI *8 TON NO ALCOHOL TO EKITAI SANSO O
 TSUNDEITA) (TSUMU AE (SORE POSTP WA) PU (NENRYO POSTP NI) A
E (ALCOHOL POSTP O *AND (SANSO ST (EKITAI)) MSR (TON POSTP N
O QU (*8 FORM ORG))) AUX (IRU TNS PAST) TNS PAST) NIL))

*rtime
(0.32900000 SECS)
```

The remainder of this session continues in Appendix C.

3.Translation Rules

Translation, or mapping rules, that transform SRs of English to get SRs of Japanese, consist of four parts. Top level procedures and structure transformation rules are shown in Table 3.1. Casename and vocabulary translation rules are given in Appendix B.

Of top level procedures, TRANSLATE tries to REPLACE the head of its SR, then calls TRANSPAIR to translate the SR's argument pairs (casename and its structure). TRANSPAIR first attempts to REPLACE, if any, casename's structure. REPLACE seeks vocabulary transformation rules in TRANSLATE, or casename transformation rules in TRANSPAIR.

Structure tranformation rules are MEMPR, ADDPR, DEPAIR, and ADPAIR which are logic procedures used in each vocabulary and casename transformation. MEMPR checks to see if an argument pair is in the structure. DEPAIR deletes an argument pair from the

structure. ADDPR and ADPAIR add argument pairs into the structure.

```
(1) Top Level Procedures

(((TRANSLATE (S . R) (S1 . R2))
  <
  (REPLACE S R (S1 . R1))
  (TRANSPAIR R1 (S1 . R1) R2))
 ((TRANSLATE X Y) < (ATOM* X) (REPLACE X NIL Y)))

(((TRANSPAIR (X V . R) (S1 . R1) (Y V2 . R2))
  <
  (REPLACE X V (Y . V1))
  (TRANSLATE V1 V2)
  (TRANSPAIR R (S1 . R1) R2))
 ((TRANSPAIR NIL X NIL)))

(((REPLACE X Y (U . Y1)) < (X JP U Y Y1))
 ((REPLACE X NIL X))
 ((REPLACE X W (X . W))))


(2) Structure Transformation Rules

(((MEMPR (R X) (R X . Z)))
 ((MEMPR (R X) (U V . Z)) < (MEMPR (R X) Z)))

(((DEPAIR X NIL NIL))
 ((DEPAIR (X Y) (X Y . W) W))
 ((DEPAIR (X Y) (U V . W) (U V . Z)) < (DEPAIR (X Y) W Z)))

(((ADDPR (R X) Y Y) < (MEMPR (R X) Y))
 ((ADDPR (R X) NIL (R X)))
 ((ADDPR (R X) V (R X . V))))

(((ADPAIR (R X) NIL (R X)))
 ((ADPAIR (R X) (U V . Q) (U V . Z)) < (ADPAIR (R X) Q Z)))
```

Table 3.1 Translation Rules (part 1 and 2)

We will look at some features of the Japanese as we watch vocabulary and case transformation rules, which employ the above functions, MEMPR, DEPAIR, ADDPR, and ADPAIR.

(1) Noun

Generally handling a noun is just replacing this noun with the Japanese counterpart, and deleting NumBeR and DETerminer features (See the example ST1 below.).

However, a countable noun when it has QUantity in its structure is dealt quite differently. It requires a counting feature depending on each noun; thus it needs to change its structure(See the example ST6 in appendix D). All the countable nouns have this property, so that the all vocabulary rules must provide this feature.

A complex noun like "earth mounds", whose Japanese counterpart is only one noun, "dote", has also an interesting feature. The TYPE feature must be deleted from the structure whose head is "mound" when replacing "mound" with "dote". (See the example ST5 in appendix D.)

(2) Adjective

In the grammar, there are two forms of adjective: ORiGinal and CONTinuing. Translating adjectives from English to Japanese requires two cases, whether it has *and or not. If it has *and, FORM CONT is added, otherwise FORM ORG, it is then translated with a lexical rule.

(3) Verb

In general, the verb can simply be replaced with the Japanese equivalent when there is TeNSe pair in the structure(See ST6). When there is *AND in the structure, however, FORM CONT is added (See ST5). An AUXiliary may be added to the Japanese to indicate that the verb shows continuation of action (See ST1,ST2).

(4) Preposition

Prepositions, indicating LOCations, may require complex mappings. When case name LOCation has a PREPosition pair in it, its head is replaced by this preposition, POSTPosition NI is added and the original LOC structure is embedded in this LOC. (See ST1 below) Afterwards the preposition will be replaced by a Japanese word.

Prepositions inside PUrpose and APpearance are just replaced by PUSTPosition NI. (See ST6, ST9 in Appendix D.) While these sentences show only a few examples of prepositional translation, their patterns prepare the way to handle other prepositions.

Translation examples are from the recordings of a console session. First we look at the original SRs of English, then we call TRY to translate them, by applying translation rules to the SRs and returning the translated SRs of Japanese. We pretty-print the output, and ask for RTIME. Comments appear in the same form <<....>>. The sample session follows below:

```
==========================================================

*st1
  << ST1 contains SR of English of the sentence 1 in rocket
     story. The variable U will be bound to the translated
     SRs.>>
(TRANSLATE (STAND AE (ROCKET DET A SIZE (GREAT) COLOR (BLACK
 *AND (YELLOW)) TYPE (V-2) LGTH (LONG MSR (FOOT QU (FORTY-SI
X) NBR PL)) NBR SING SNTRL SUB) TNS PAST LOC (DESERT PREP IN
 DET A LOC (NEWMEXICO) NBR SING)) U)

*(try st1)

  << We called TRY to translate ST1. Each CONTINUE questions
     100 subquestions.>>
CONTINUE? *y

CONTINUE? *y

((TRANSLATE (STAND AE (ROCKET DET A SIZE (GREAT) COLOR (BLAC
K *AND (YELLOW)) TYPE (V-2) LGTH (LONG MSR (FOOT QU (FORTY-S
```

```
IX) NBR PL)) NBR SING SNTRL SUB) TNS PAST LOC (DESERT PREP I
N DET A LOC (NEWMEXICO) NBR SING)) (TATSU AE (ROCKET POSTP W
A SIZE (OHKII FORM ORG) COLOR (KUROI FORM CONT *AND (KIIROI
FORM ORG)) TYPE (V-2) LGTH (NAGASA POSTP NO MSR (FEET POSTP
NO QU (*46 FORM ORG)))) LOC (NAKA POSTP NI LOC (SABAKU POSTP
 NO LOC (NEWMEXICO))) AUX (IRU TNS PAST) TNS PAST)))

  << We pretty-print the output. See the following.
       Verb (AUX) transformation, ordinary noun,
       adjectives (both cases), preposition handling (LOC)
       including English word IN changes into NAKA.
       Also SNTRL SUB changes to POSTP WA.>>
*(sprint (car val))
(TRANSLATE (STAND AE
                    (ROCKET DET
                            A
                            SIZE
                            (GREAT)
                            COLOR
                            (BLACK *AND (YELLOW))
                            TYPE
                            (V-2)
                            LGTH
                            (LONG MSR
                                 (FOOT QU (FORTY-SIX) NBR PL))
                            NBR
                            SING
                            SNTRL
                            SUB)
                    TNS
                    PAST
                    LOC
                    (DESERT PREP
                            IN
                            DET
                            A
                            LOC
                            (NEWMEXICO)
                            NBR
                            SING))
             (TATSU AE
                    (ROCKET POSTP
                            WA
                            SIZE
                            (OHKII FORM ORG)
                            COLOR
```

```
                                (KUROI FORM
                                       CONT
                                       *AND
                                       (KIIROI FORM ORG))
                                TYPE
                                (V-2)
                                LGTH
                                (NAGASA POSTP
                                        NO
                                        MSR
                                        (FEET POSTP
                                              NO
                                              QU
                                              (*46 FORM ORG))))
                         LOC
                         (NAKA POSTP
                               NI
                               LOC
                               (SABAKU POSTP NO LOC (NEWMEXICO)))
                         AUX
                         (IRU TNS PAST)
                         TNS
                         PAST))
NIL
*rtime
(0.85500000 SECS)
  << It took real CPU time 0.855 secs.>>

*st3
(TRANSLATE (CARRY PU (FUEL PREP FOR NBR SING) AE (IT NBR SIN
G SNTRL SUB) TNS PAST AE (ALCOHOL MSR (TON PREP OF QU (EIGHT
) NBR PL) NBR SING *AND (OXYGEN ST (LIQUID) NBR SING) SNTRL
OBJ)) V)

*(sprint (car (try st3)))

CONTINUE? *y

  << Sentence 3 demonstrates the features following;
     Prepostion handling (purpose)==> POSTP NI.
     SNTRL OBJ (AE) ==> POSTP O .>>
(TRANSLATE (CARRY PU
                  (FUEL PREP FOR NBR SING)
                  AE
                  (IT NBR SING SNTRL SUB)
                  TNS
```

```
                    PAST
                    AE
                    (ALCOHOL MSR
                             (TON PREP OF QU (EIGHT) NBR PL)
                             NBR
                             SING
                             *AND
                             (OXYGEN ST (LIQUID) NBR SING)
                             SNTRL
                             OBJ))
          (TSUMU PU
                    (NENRYO POSTP NI)
                    AE
                    (SORE POSTP WA)
                    AE
                    (ALCOHOL POSTP
                             O
                             MSR
                             (TON POSTP NO QU (*8 FORM ORG))
                             *AND
                             (SANSO ST (EKITAI)))
                    AUX
                    (IRU TNS PAST)
                    TNS
                    PAST))
NIL

*rtime
(0.37600000 SECS)
```

The remainder of this session continues in Appendix D.

4.Conclusions

We have watched the method of translating from English to Japanese. Once we have an English grammar to parse English sentences into semantic relations, we can use the translation rules in Appendix B to map the SRs of English to those of Japanese and use the Japanese grammar in Appendix A to generate Japanese sentences from the SRs of Japanese.

Generally for translation between languages, a symmetric grammar (i.e. usable both for parsing and generation) for each language and a set of rules from terms of one language to those of the other one are required. In this report, two important things are the properties of symmetry and transferability. We do not need two programs for one language, one to parse the sentence into semantic relations and another to generate a sentence from the semantic relations. Because of the property of symmetry, we could translate Japanese to English by adding only translation rules, which could be constructed in the same fashion (maybe with

the help of the structure transformation rules) as the one presented here. An open research question is the possibility of symmetric translation rules. Can one translation grammar map SRs in both directions between a pair of languages?

Transferability of the structure of the SR between languages is also important. In section one, it was said that for the computational approach to translate, there should be deep structures for the sentences of each language. It is easier to use this method than to use direct sentence-to-sentence translation, because there are a lot of semantic differences on the sentence level while there are few on the semantic relation level.

However, there is still a problem with the Japanese grammar. It is not as general a grammar as the English one because the sentence structure (S11, S12,..) allows only up to four phrases in one sentence and the modified noun phrase(MDNP) allows up to three level. They limit their entries. They should accept as many entries as possible. And a problem is also found in the translation rules. ST10 (It was too high to be seen.) is an example. Because of the language differences, Japanese say "It was so high that we could not see it."(a literal English

paraphrase of the Japanese), but Japanese do not say "It was too nigh to be seen." Translation rules, which only map SRs to SRs, become very complex. We need to perform deeper level translation.

For further research, a more general symmetric grammar of Japanese has to be developed and the translation has to be considered at a deeper conceptual level.

Appendix A.Japanese Grammar

(1) Grammar rules

```
(((S1 X Y R) < (S11 X Y R))
 ((S1 X Y R) < (S12 X Y R))
 ((S1 X Y R) < (S13 X Y R))
 ((S1 X Y R) < (S14 X Y R)))

 (((S2 X (V1 *AND V2 . Q) R)
   <
   (S1 X (V1 . Q) R1)
   (S1 R1 V2 R)))

 (((S3 X (V2 W V1 . Q) R)
   <
   (S1 X V1 (R1 . R2))
   (POSTP R1)
   (S1 R2 (V2 . Q) R3)
   (FEAT V1 X1)
   (FEAT V2 X2)
   (ARCVAL X2 X1 R1 W)))

 (((S11 X (Z W1 V1 . Z1) R)
   <
   (PHR X V1 R1)
   (VP R1 (Z . Z1) R)
   (SEMP Z V1 W1)))

 (((S12 X (Z W1 V1 W2 V2 . Z1) R)
   <
   (PHR X V1 R1)
   (PHR R1 V2 R2)
   (VP R2 (Z . Z1) R)
```

```
  (SEMF Z V1 W1)
  (SEMF Z V2 W2)))

(((S13 X (Z W1 V1 W2 V2 W3 V3 . Z1) R)
  <
  (PHR X V1 R1)
  (PHR R1 V2 R2)
  (PHR R2 V3 R3)
  (VP R3 (Z . Z1) R)
  (SEMF Z V1 W1)
  (SEMF Z V2 W2)
  (SEMF Z V3 W3)))

(((S14 X (Z W1 V1 W2 V2 W3 V3 W4 V4 . Z1) R)
  <
  (PHR X V1 R1)
  (PHR R1 V2 R2)
  (PHR R2 V3 R3)
  (PHR R3 V4 R4)
  (VP R4 (Z . Z1) R)
  (SEMF Z V1 W1)
  (SEMF Z V2 W2)
  (SEMF Z V3 W3)
  (SEMF Z V4 W4)))

(((PHR X Y R) < (NP X Y R)) ((PHR X Y R) < (ADVP X Y R)))

(((NP X (Y POSTP W . Y1) R)
  <
  (NP1 X (Y . Y1) R1)
  (PP R1 W R))
 ((NP X (V1 POSTP W *AND V2 . Q) R)
  <
  (NP1 X (V1 . Q) (R1 . R2))
  (CONJ R1)
  (NP1 R2 V2 R3)
  (PP R3 W R)))

(((NP1 (X Y . R) (Y W (X)) R)
  <
  (NOUN X)
  (NOUN Y)
  (FEAT X W))
 ((NP1 (X . R) (X) R) < (NOUN X))
 ((NP1 X V R) < (MDNP X V R))
 ((NP1 X (V2 W V1 . Q) R)
```

```
   <
   (ADJP X V1 R1)
   (NP1 R1 (V2 . Q) R)
   (FEAT V1 w)))

(((NP2 (X Y . R) (Y w (X)) R)
   <
   (NOUN X)
   (NOUN Y)
   (FEAT X W))
  ((NP2 (X . R) (X) R) < (NOUN X))
  ((NP2 X (V2 W V1 . Q) R)
   <
   (ADJP X V1 R1)
   (NP2 R1 (V2 . Q) R)
   (FEAT V1 W)))

(((MDNP X
         (V3 w2
             (V2 POSTP R3 W1 (V1 POSTP R1 . Q1) . Q2) . Q3)
         R)
   <
   (NP2 X (V1 . Q1) (R1 . R2))
   (MODARC V1 W1)
   (POSTMP R1)
   (NP2 R2 (V2 . Q2) (R3 . R4))
   (MODARC V2 W2)
   (POSTMP R3)
   (NP2 R4 (V3 . Q3) R))
  ((MDNP X (V2 W1 (V1 POSTP R1 . Q1) . Q2) R)
   <
   (NP2 X (V1 . Q1) (R1 . R2))
   (MODARC V1 W1)
   (POSTMP R1)
   (NP2 R2 (V2 . Q2) R)))

(((ADVP (X Y . Z) (X *AND V1) R)
   <
   (ADV X)
   (CONJ Y)
   (ADVP Z V1 R))
  ((ADVP (X . Y) (V1 W (X) . Q) R)
   <
   (ADV X)
   (ADVP Y (V1 . Q) R)
   (FEAT X W))
```

```
 ((ADVP (X . Y) (X) Y) < (ADV X))
 ((ADVP (X . Y) (V1 W (X2) . Q) Y)
  <
  (ADV X X1 X2)
  (ADJ X1 (V1 . Q))
  (FEAT X2 W)))

(((ADJP (X . Y) (X1 FORM Y1 *AND V1) R)
  <
  (ADJ X (X1 FORM Y1))
  (EQ Y1 CONT)
  (ADJP Y V1 R))
 ((ADJP (X . Y) X1 Y) < (ADJ X X1))
 ((ADJP (X . Y) (V1 W (X) . Q) R)
  <
  (ADV X)
  (ADJP Y (V1 . Q) R)
  (FEAT X W)))

(((PP (X . Y) X Y) < (POSTP X)))

(((PPTEST X (Y POSTP W1 . Q) W)
  <
  (FEAT X X1)
  (FEAT Y Y1)
  (ARCVAL X1 Y1 W1 W)))

(((VP (X Y . Z) (V2 W V1 . Q) Z)
  <
  (VV X V1)
  (VV Y (V2 . Q))
  (FEAT V1 W))
 ((VP (X . Y) X1 Y) < (VV X X1))
 ((VP (X . Y) (V AUX V1 . Q) Y)
  <
  (VBP X X1 X2)
  (VV X1 (V . Q))
  (VBE X2 V1)))

(((VBP TATTEITA TATTA ITA))
 ((VBP TSUNDEITA TSUNDA ITA))
 ((VBP UCHIAGERARETE UCHIAGERU RARETE))
 ((VBP MIENAKUNARU MIENAI NARU)))

(((SEMF X (Y . Y1) W) < (ADV Y) (FEAT Y W))
 ((SEMF X (Y . Y1) W) < (ADJ Y V1) (FEAT Y W))
```

```
((SEMF X Y W) < (PPTEST X Y W)))
```

(2) Lexical Assertions

```
(((NOUN NAGASA))
 ((NOUN V-2))
 ((NOUN ROCKET))
 ((NOUN NEWMEXICO))
 ((NOUN SABAKU))
 ((NOUN KARA))
 ((NOUN TON))
 ((NOUN OMOSA))
 ((NOUN NENRYO))
 ((NOUN ALCOHOL))
 ((NOUN EKITAI))
 ((NOUN SANSO))
 ((NOUN JUMSI))
 ((NOUN KAGAKUSHA))
 ((NOUN SHOGUN))
 ((NOUN DOTE))
 ((NOUN USHIRO))
 ((NOUN NAKA))
 ((NOUN HONOH))
 ((NOUN SHINGO))
 ((NOUN AIZU))
 ((NOUN OTO))
 ((NOUN FEET))
 ((NOUN HOSHI))
 ((NOUN RADAR))
 ((NOUN MPH))
 ((NOUN HAYASA))
 ((NOUN TEISATSUKI))
 ((NOUN PILOT))
 ((NOUN HASSHA))
 ((NOUN CHITEN))
 ((NOUN TOKORO))
 ((NOUN SORE))
 ((NOUN SUBETE))
 ((NOUN HON))
 ((NOUN MILE))
 ((NOUN BYOH))
 ((NOUN NOCHI))
 ((NOUN HUN)))

(((ADJ OHKII (OHKII FORM DRG)))
```

```
 ((ADJ KIIROI (KIIROI FORM ORG)))
 ((ADJ AKAI (AKAI FORM ORG)))
 ((ADJ KUROKU (KUROI FORM CONT)))
 ((ADJ *46 (*46 FORM ORG)))
 ((ADJ *5 (*5 FORM ORG)))
 ((ADJ *8 (*8 FORM ORG)))
 ((ADJ *2 (*2 FORM ORG)))
 ((ADJ *3000 (*3000 FORM ORG)))
 ((ADJ *60 (*60 FORM ORG)))
 ((ADJ *40 (*40 FORM ORG)))
 ((ADJ SU (SU FORM ORG)))
 ((ADJ TAKAI (TAKAI FORM ORG))))

(((ADV SUKOSHI))
 ((ADV SUGUNI))
 ((ADV YUKKURI))
 ((ADV DANDAN))
 ((ADV HAYAKU))
 ((ADV TAKASUGITE TAKAI SUGITE)))

(((POSTP NI))
 ((POSTP WA))
 ((POSTP GA))
 ((POSTP O))
 ((POSTP DE))
 ((POSTP MADE)))

(((POSTMP NO)) ((POSTMP KARA)))

(((VV OCHITA (OCHIRU TNS PAST)))
 ((VV MITA (MIRU TNS PAST)))
 ((VV OTTA (OU TNS PAST)))
 ((VV MIETA (MIERU TNS PAST)))
 ((VV HIITA (HIKU TNS PAST)))
 ((VV AGATTA (AGARU TNS PAST)))
 ((VV SUWATTA (SUWARU TNS PAST)))
 ((VV NATTA (NARU TNS PAST)))
 ((VV ATTA (ARU TNS PAST)))
 ((VV DEKITA (DEKIRU TNS PAST)))
 ((VV UCHIAGERU (UCHIAGERU TNS PRES)))
 ((VV TASSURU (TASSURU TNS PRES)))
 ((VV MODORU (MODORU TNS PRES)))
 ((VV IATTA (TATSU TNS PAST)))
 ((VV TSUNDA (TSUMU TNS PAST)))
 ((VV HANARERU (HANARERU TNS PRES)))
 ((VV TOMONAU (TOMONAU TNS PRES)))
```

```
 ((VV MIENAKU (MIERU FORM CONT MOD NEG TNS PRES)))
 ((VV OIKAKETA (OIKAKERU TNS PAST)))
 ((VV HANARETE (HANARERU FORM CONT TNS PAST)))
 ((VV TOMONAITTE (TOMONAU FORM CONT TNS PAST))))

(((VBE ITA (IRU TNS PAST)))
 ((VBE RARETE (RARERU TNS PRES))))

(((CONJ TO)) ((CONJ SOSHITE)))

(((MODARC Y W) < (FEAT Y Y1) (ARCNAME Y1 W)))

(((ARCNAME HUMAN POS))
 ((ARCNAME DEV ASSOC))
 ((ARCNAME LOC LOC))
 ((ARCNAME MSR MSR))
 ((ARCNAME LGTH LGTH))
 ((ARCNAME WGT WGT))
 ((ARCNAME POBJ ASSOC))
 ((ARCNAME DGR DGR))
 ((ARCNAME TIME TIME))
 ((ARCNAME RATE RATE)))

(((ARCVAL POSIT POBJ GA AE))
 ((ARCVAL POSIT LOC NI LOC))
 ((ARCVAL MSR ST OE ST))
 ((ARCVAL MSR WGT GA WGT))
 ((ARCVAL MSR POBJ WA AE))
 ((ARCVAL CO POBJ WA AE))
 ((ARCVAL CO POBJ NI PU))
 ((ARCVAL CO POBJ O AE))
 ((ARCVAL ST DGR GA AE))
 ((ARCVAL ST POBJ GA AE))
 ((ARCVAL ST TIME NI TIME))
 ((ARCVAL ST POBJ WA AE))
 ((ARCVAL MOVE HUMAN WA AGT))
 ((ARCVAL MOVE POBJ WA AE))
 ((ARCVAL MOVE LOC NI LOC))
 ((ARCVAL MOVE POBJ GA AE))
 ((ARCVAL MOVE POBJ NI PU))
 ((ARCVAL AC SOUND O AC))
 ((ARCVAL ACT LOC NI LOC))
 ((ARCVAL ACT POBJ WA INSTR))
 ((ARCVAL ACT POBJ O AE))
 ((ARCVAL AP POBJ WA AE))
 ((ARCVAL AP POBJ NI AP))
```

```
 ((ARCVAL AP DEV WA INSTR))
 ((ARCVAL MOVE SP NI SP))
 ((ARCVAL AP HUMAN WA AGT))
 ((ARCVAL ACT POBJ GA INSTR))
 ((ARCVAL AP MOVE MADE DUR)))

(((FEAT OHKII SIZE))
 ((FEAT KIIROI COLOR))
 ((FEAT AKAI COLOR))
 ((FEAT KUROI COLOR))
 ((FEAT SUGITE INTENS))
 ((FEAT TAKAI HT))
 ((FEAT SUKOSHI DGR))
 ((FEAT SUGUNI TIME))
 ((FEAT YUKKURI RATE))
 ((FEAT DANDAN DGR))
 ((FEAT HAYAKU RATE))
 ((FEAT NAGASA LGTH))
 ((FEAT V-2 TYPE))
 ((FEAT ROCKET POBJ))
 ((FEAT NEWMEXICO LOC))
 ((FEAT SABAKU LOC))
 ((FEAT KARA ST))
 ((FEAT TON MSR))
 ((FEAT OMOSA WGT))
 ((FEAT NENRYO POBJ))
 ((FEAT ALCOHOL POBJ))
 ((FEAT EKITAI ST))
 ((FEAT SANSO POBJ))
 ((FEAT JUMBI POBJ))
 ((FEAT KAGAKUSHA HUMAN))
 ((FEAT SHOGUN HUMAN))
 ((FEAT DOTE LOC))
 ((FEAT USHIRO LOC))
 ((FEAT NAKA LOC))
 ((FEAT HONOH POBJ))
 ((FEAT SHINGO POBJ))
 ((FEAT AIZU POBJ))
 ((FEAT OTO SOUND))
 ((FEAT FEET MSR))
 ((FEAT HOSHI POBJ))
 ((FEAT RADAR DEV))
 ((FEAT MPH RATE))
 ((FEAT HAYASA SP))
 ((FEAT TEISATSUKI POBJ))
 ((FEAT PILOT HUMAN))
```

```
((FEAT HASSHA TYPE))
((FEAT CHITEN LOC))
((FEAT TOKORO LOC))
((FEAT MILE MSR))
((FEAT SORE POBJ))
((FEAT SUBETE DGR))
((FEAT *46 QU))
((FEAT *5 QU))
((FEAT *8 QU))
((FEAT *2 QU))
((FEAT *60 QU))
((FEAT *3000 QU))
((FEAT *40 QU))
((FEAT BYOH TIME))
((FEAT NOCHI TIME))
((FEAT HUN TIME))
((FEAT SU QU))
((FEAT HON MSR))
((FEAT OCHIRU ACT))
((FEAT MIRU AP))
((FEAT OU AP))
((FEAT MIERU AP))
((FEAT HIKU ACT))
((FEAT AGARU MOVE))
((FEAT SUWARU MOVE))
((FEAT ARU MSR))
((FEAT DEKIRU ST))
((FEAT UCHIAGERU ACT))
((FEAT TASSURU MOVE))
((FEAT MODORU ACT))
((FEAT TATSU POSIT))
((FEAT TSUMU CO))
((FEAT HANARERU MOVE))
((FEAT TOMONAU AC))
((FEAT OIKAKERU AP))
((FEAT MIENAI AP))
((FEAT NARU ST))
((FEAT (X . Y) W) < (FEAT X W)))
```

Appendix B.Translation Rules

(3) Case Transformation Rules

```
(((LOC JP LOC (W . Y) (W . Y)) < (MEMPR (PREP TO) Y))
 ((LOC JP LOC (W . Y) (X POSTP NI LOC (W . Y1)))
  <
  (MEMPR (PREP X) Y)
  (DEPAIR (PREP X) Y Y2)
  (ADDPR (POSTP NO) Y2 Y1)))

(((PU JP PU (W . Y) (W . Y1))
  <
  (MEMPR (PREP X) Y)
  (DEPAIR (PREP X) Y Y2)
  (ADDPR (POSTP NI) Y2 Y1))
 ((PU JP PU (W . Y) (W . Y1))
  <
  (MEMPR (INF TO) Y)
  (DEPAIR (INF TO) Y Y2)
  (ADDPR (POSTP NO) Y2 Y3)
  (ADDPR (POSTP TAME) Y3 Y1)))

(((MSR JP MSR (W . Y) (W . Y1))
  <
  (DEPAIR (PREP OF) Y Y2)
  (ADDPR (POSTP NO) Y2 Y1)))

(((AGT JP AGT (W . Y) (W . Y1))
  <
  (MEMPR (SNTRL OBJ) Y)
  (DEPAIR (SNTRL OBJ) Y Y2)
  (ADDPR (SNTRL OBJP) Y2 Y1))
 ((AGT JP AGT (W . Y) (W . Y1))
  <
```

```
  (MEMPR (SNTRL SUB) Y)
  (DEPAIR (SNTRL SUB) Y Y2)
  (ADDPR (SNTRL SUB) Y2 Y1)))

(((AE JP AE (W . Y) (W . Y1))
  <
  (MEMPR (SNTRL OBJ) Y)
  (DEPAIR (SNTRL OBJ) Y Y2)
  (ADDPR (SNTRL OBJO) Y2 Y1))
 ((AE JP AE (W . Y) (W . Y1))
  <
  (MEMPR (SNTRL SUB) Y)
  (DEPAIR (SNTRL SUB) Y Y2)
  (ADDPR (SNTRL SUB) Y2 Y1)))

(((AP JP AP (W . Y) (W . Y1))
  <
  (MEMPR (PREP X) Y)
  (DEPAIR (PREP X) Y Y2)
  (ADDPR (POSTP NI) Y2 Y1)))

(((SUBST JP SUBST (W . Y) (W . Y1))
  <
  (MEMPR (SNTRL OBJ) Y)
  (DEPAIR (SNTRL OBJ) Y Y2)
  (ADDPR (SNTRL OBJO) Y2 Y1)))

(((SNTRL JP POSTP Y Y1) < (POSTP Y Y1)))

(((POSTP SUB WA)) ((POSTP OBJP NI)) ((POSTP OBJO O)))
```

(4) Vocabulary Transformation Rules

```
(((IT JP SORE Y Y1) < (DEPAIR (NBR X) Y Y1)))

(((SOON JP SUGUNI Y Y)))

(((BLACK JP KUROI Y Y1)
  <
  (MEMPR (*AND X) Y)
  (ADDPR (FORM CONT) Y Y1))
 ((BLACK JP KUROI Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((GREAT JP OHKII Y Y1)
```

```
  <
  (MEMPR (*AND X) Y)
  (ADDPR (FORM CONT) Y Y1))
 ((GREAT JP OHKII Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((YELLOW JP KIIROI Y Y1)
  <
  (MEMPR (*AND X) Y)
  (ADDPR (FORM CONT) Y Y1))
 ((YELLOW JP KIIROI Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((RED JP AKAI Y Y1)
  <
  (MEMPR (*AND X) Y)
  (ADDPR (FORM CONT) Y Y1))
 ((RED JP AKAI Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((FORTY-SIX JP *46 Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((EIGHT JP *8 Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((SIXTY JP *60 Y Y1) < (ADDPR (FORM ORG) Y Y1)))

(((DESERT JP SABAKU Y Y1)
  <
  (DEPAIR (DET X) Y Y2)
  (DEPAIR (NBR X1) Y2 Y1)))

(((FUEL JP NENRYO Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((ALCOHOL JP ALCOHOL Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((OXYGEN JP SANSO Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((LIQUID JP EKITAI Y Y1) < (DEPAIR (DET X) Y Y1)))

(((TON JP TON Y Y1)
```

```
  <
  (DEPAIR (NBR X) Y Y2)
  (MEMPR (QU X1) Y2)
  (ADDPR (POSTP NO) Y2 Y1)))

(((SCIENTIST JP KAGAKUSHA Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((GENERAL JP SHOGUN Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((DISTANCE JP TOHKUNI Y Y1)
  <
  (MEMPR (PREP TO) Y)
  (DEPAIR (PREP TO) Y Y2)
  (DEPAIR (NBR X) Y2 Y3)
  (DEPAIR (DET X1) Y3 Y1)))

(((MOUND JP DOTE Y Y1)
  <
  (MEMPR (TYPE X) Y)
  (DEPAIR (TYPE X) Y Y2)
  (DEPAIR (NBR X1) Y2 Y3)
  (DEPAIR (DET X2) Y3 Y1)))

(((FLAME JP HONOH Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((SIGNAL JP AIZU Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((FLARE JP HONOH Y Y1)
  <
  (MEMPR (QU (X)) Y)
  (DEPAIR (NBR X1) Y Y2)
  (DEPAIR (DET X2) Y2 Y3)
  (CNTFEAT FLARE W)
  (W X W1)
```

```
  (DEPAIR (QU (X)) Y3 Y4)
  (ADDPR (MSR (W1 POSTP NO QU (X))) Y4 Y1))
 ((FLARE JP HONOH Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((FOOT JP FEET Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (MEMPR (QU X1) Y2)
  (ADDPR (POSTP NO) Y2 Y1)))

(((LONG JP NAGASA Y Y1)
  <
  (MEMPR (MSR X) Y)
  (ADDPR (POSTP NO) Y Y1)))

(((ROCKET JP ROCKET Y Y1)
  <
  (DEPAIR (DET X) Y Y2)
  (DEPAIR (NBR X1) Y2 Y1)))

(((STAR JP HOSHI Y Y1)
  <
  (DEPAIR (NBR X) Y Y2)
  (DEPAIR (DET X1) Y2 Y1)))

(((BEHIND JP USHIRO Y Y1) < (ADDPR (POSTP NI) Y Y1)))

(((IN JP NAKA Y Y1) < (ADDPR (POSTP NI) Y Y1)))

(((ON JP UE Y Y1) < (ADDPR (POSTP NI) Y Y1)))

(((STAND JP TATSU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (ADPAIR (AUX (IRU TNS X)) Y Y2)
  (DEPAIR (TNS X) Y2 Y3)
  (ADPAIR (TNS X) Y3 Y1)))

(((CARRY JP TSUMU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (ADPAIR (AUX (IRU TNS X)) Y Y2)
  (DEPAIR (TNS X) Y2 Y3)
```

```
  (ADPAIR (TNS X) Y3 Y1)))

(((RISE JP AGARU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (ADPAIR (TNS X) Y2 Y1)))

(((FIRE JP UCHIAGERU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (ADPAIR (TNS X) Y2 Y1)))

(((WITHDRAW JP HANARERU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (MEMPR (*AND X1) Y2)
  (ADPAIR (FORM CONT) Y2 Y3)
  (ADPAIR (TNS X) Y3 Y1)))

(((TRAIL JP HIKU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (ADPAIR (TNS X) Y2 Y1)))

(((CROUCH JP SUWARU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (ADPAIR (TNS X) Y2 Y1)))

(((LOOK JP MIERU Y Y1)
  <
  (MEMPR (TNS X) Y)
  (DEPAIR (TNS X) Y Y2)
  (ADPAIR (TNS X) Y2 Y1)))

(((CNTFEAT ROCKET CNT1)) ((CNTFEAT FLARE CNT2)))

(((CNT1 X DAI)))

(((CNT2 ONE PON)) ((CNT2 TWO HON)) ((CNT2 THREE BON)))
```

Appendix C.Japanese Sentence Analysis

The following is a continuation of the recording session in section 2.

```
*(sprint st8)
(S13 (SORE WA USHIRO NI *60 FEET NO KIIROI HONOH O HIITA)
     X
     X1)
NIL
  << We call TRY to parse sentence 8, and pretty-print
     the output.>>

*(sprint (car (try st8)))

CONTINUE? *y

(S13 (SORE WA USHIRO NI *60 FEET NO KIIROI HONOH O HIITA)
     (HIKU INSTR
           (SORE POSTP WA)
           LOC
           (USHIRO POSTP NI)
           AE
           (HONOH POSTP
                  O
                  MSR
                  (FEET POSTP NO QU (*60 FORM ORG))
                  COLOR
                  (KIIROI FORM ORG))
           TNS
           PAST)
     NIL)
NIL

*rtime
```

```
(0.87200000 SECS)
  << We set J to (S13 x semantic-relation nil) to show the
     symmetry of the grammar again.>>

*(setq j (car (subst x (cadar val) val)))
(S13 _X (HIKU INSTR (SORE POSTP WA) LOC (USHIRO POSTP NI) AE
 (HONOH POSTP O MSR (FEET POSTP NO QU (*60 FORM ORG)) COLOR
(KIIROI FORM ORG)) TNS PAST) NIL)

*(try j)
((S13 (SORE WA USHIRO NI *60 FEET NO KIIROI HONOH O HIITA) (
HIKU INSTR (SORE POSTP WA) LOC (USHIRO POSTP NI) AE (HONOH P
OSTP O MSR (FEET POSTP NO QU (*60 FORM ORG)) COLOR (KIIROI F
ORM ORG)) TNS PAST) NIL))

*rtime
(0.57300000 SECS)

*(sprint st9)
(S13 (SUGUNI HONOH WA KIIROI HOSHI NI MIETA) X X1)
NIL
  << We TRY to parse sentence 9.>>

*(sprint (car (try st9)))

CONTINUE? *y

(S13 (SUGUNI HONOH WA KIIROI HOSHI NI MIETA)
     (MIERU TIME
            (SUGUNI)
            AE
            (HONOH POSTP WA)
            AP
            (HOSHI POSTP NI COLOR (KIIROI FORM ORG))
            TNS
            PAST)
     NIL)
NIL

*rtime
(0.94800000 SECS)

*(setq j (car (subst x (cadar val) val )))
(S13 _X (MIERU TIME (SUGUNI) AE (HONOH POSTP WA) AP (HOSHI P
OSTP NI COLOR (KIIROI FORM ORG)) TNS PAST) NIL)
```

```
  << we show the symmetry of the grammar.>>

*(try j)
((S13 (SUGUNI HONOH WA KIIROI HOSHI NI MIETA) (MIERU TIME (S
UGUNI) AE (HONOH POSTP WA) AP (HOSHI POSTP NI COLOR (KIIROI
FORM ORG)) TNS PAST) NIL))

*rtime
(0.18300000 SECS)

*(sprint st13)
(S12 (SORE WA HASSHA CHITEN KARA *40 MILE NO TOKORO NI
            OCHITA)
     X
     X1)
NIL

  << we TRY to parse sentence 13 and get pretty-print
     output.>>
*(sprint (car (try st13)))
(S12 (SORE WA HASSHA CHITEN KARA *40 MILE NO TOKORO NI
            OCHITA)
     (OCHIRU INSTR
             (SORE POSTP WA)
             LOC
             (TOKORO POSTP
                     NI
                     MSR
                     (MILE POSTP
                           NO
                           LOC
                           (CHITEN POSTP KARA TYPE (HASSHA))
                           QU
                           (*40 FORM ORG)))
             TNS
             PAST)
     NIL)
NIL

*rtime
(0.68300000 SECS)

*(setq j (car (subst x (cadar val ) val)))
(S12 _X (OCHIRU INSTR (SORE POSTP WA) LOC (TOKORO POSTP NI M
SR (MILE POSTP NO LOC (CHITEN POSTP KARA TYPE (HASSHA)) QU (
*40 FORM ORG))) TNS PAST) NIL)
```

```
*(try j)
((S12 (SORE WA HASSHA CHITEN KARA *40 MILE NO TOKORO NI OCHI
TA) (OCHIRU INSTR (SORE POSTP WA) LOC (TOKORO POSTP NI MSR (
MILE POSTP NO LOC (CHITEN POSTP KARA TYPE (HASSHA)) QU (*40
FORM ORG))) TNS PAST) NIL))

*rtime
(0.27400000 SECS)

  << That is the end of the session.>>
```

Appendix D.Translation Analysis

The following is the continuation of the recording session in section 3.

```
*st5
(TRANSLATE (WITHDRAW AGT (SCIENTIST NBR PL *AND (GENERAL NBR
 PL) SNTRL SUB) TNS PAST LOC (DISTANCE PREP TO DET SOME NBR
SING) *AND (CROUCH TNS PAST LOC (MOUND PREP BEHIND TYPE (EAR
TH NBR SING) NBR PL))) V)

*(sprint (car (try st5)))

CONTINUE? *y

  << We can see the following features from this example.
      Preposition (LOC) is different here, because of TO.
      DOTE (noun) is a composite form in Japanese. It
      consists of MOUND and TYPE earth in English.
      Verb contains *and in the structure transforms into
      Verb + TNS + FORM CONTinuing.>>
(TRANSLATE (WITHDRAW AGT
                     (SCIENTIST NBR
                                PL
                                *AND
                                (GENERAL NBR PL)
                                SNTRL
                                SUB)
                     TNS
                     PAST
                     LOC
                     (DISTANCE PREP TO DET SOME NBR SING)
                     *AND
                     (CROUCH TNS
                             PAST
```

```
                                        LOC
                                        (MOUND PREP
                                               BEHIND
                                               TYPE
                                               (EARTH NBR SING)
                                               NBR
                                               PL)))
                    (HANARERU AGT
                              (KAGAKUSHA POSTP WA *AND (SHOGUN))
                              LOC
                              (TOHKUNI)
                              *AND
                              (SUWARU LOC
                                      (USHIRO POSTP
                                              NI
                                              LOC
                                              (OOTE POSTP NO))
                                      TNS
                                      PAST)
                              FORM
                              CONT
                              TNS
                              PAST))
NIL

*rtime
(0.57100000 SECS)

*st6
(TRANSLATE (RISE AE (FLARE QU (TWO) COLOR (RED) NBR PL SNTRL
 SUB) TNS PAST PU (SIGNAL PREP AS DET A PU (FIRE INF TO TNS
PRES AE (ROCKET DET THE NBR SING)) NBR SING)) V)

*(sprint (car (try st6)))

CONTINUE? *y
  << We have the following features in this translation.>>
  << Noun + QU transforms Noun + MSR ( QU ) as described
     in section 3.>>
  << Preposition in PUrpose is changed into POSTP NI.>>

(TRANSLATE (RISE AE
                 (FLARE QU
                        (TWO)
                        COLOR
                        (RED)
```

```
                NBR
                PU
                SNTRL
                SUB)
        TNS
        PAST
        PU
        (SIGNAL PREP
                AS
                DET
                A
                PU
                (FIRE INF
                      TO
                      TNS
                      PRES
                      AE
                      (ROCKET DET
                              THE
                              NBR
                              SING
                              SNTRL
                              OBJ))
                NBR
                SING))
(AGARU AE
       (HONDH MSR
              (HON POSTP NO QU (TWO))
              POSTP
              WA
              COLOR
              (AKAI FORM ORG))
       PU
       (AIZU POSTP
             NI
             PU
             (UCHIAGERU POSTP
                        TAME
                        POSTP
                        NO
                        AE
                        (ROCKET POSTP O))
                        TNS
                        PRES))
       TNS
       PAST))
```

```
NIL

*rtime
(0.40100000 SECS)

*st8
(TRANSLATE (TRAIL LOC BEHIND INSTR (IT NBR SING SNTRL SUB) T
NS PAST SUBST (FLAME MSR (FOOT PREP OF QU (SIXTY) NBR PL) CO
LOR (YELLOW) NBR SING SNTRL OBJ)) V)

*(sprint (car (try st8)))

CONTINUE? *y

  << Following features are presented.>>
  << Preposition (LOC).>>
(TRANSLATE (TRAIL LOC
                  BEHIND
                  INSTR
                  (IT NBR SING SNTRL SUB)
                  TNS
                  PAST
                  SUBST
                  (FLAME MSR
                         (FOOT PREP OF QU (SIXTY) NBR PL)
                         COLOR
                         (YELLOW)
                         NBR
                         SING
                         SNTRL
                         OBJ))
           (HIKU LOC
                 (USHIRO POSTP NI)
                 INSTR
                 (SORE POSTP WA)
                 SUBST
                 (HONOH POSTP
                        O
                        MSR
                        (FEET POSTP NO QU (*60 FORM ORG))
                        COLOR
                        (KIIROI FORM ORG))
                 TNS
                 PAST))
NIL
```

```
*rtime
(0.54300000 SECS)

*st9
(TRANSLATE (LOOK TIME SOON AE (FLAME DET THE NBR SING SNTRL
SUB) TNS PAST AP (STAR PREP LIKE DET A COLOR (YELLOW) NBR SI
NG)) V)

*(sprint (car (try st9)))

CONTINUE? *y

(TRANSLATE (LOOK TIME
                 SOON
                 AE
                 (FLAME DET THE NBR SING SNTRL SUB)
                 TNS
                 PAST
                 AP
                 (STAR PREP
                       LIKE
                       DET
                       A
                       COLOR
                       (YELLOW)
                       NBR
                       SING))
           (MIERU TIME
                  (SUGUNI)
                  AE
                  (HONDH POSTP WA)
                  AP
                  (HOSHI POSTP NI COLOR (KIIROI FORM ORG))
                  TNS
                  PAST))
NIL

*rtime
(0.22300000 SECS)
```

<< That is the end of the session.>>

bibliography

1. Anderson, M.John, The Grammar of Case, Cambridge Studies in Linguistics, Vol. 4, Cambridge University Press, Cambridge, 1971.
2. Beaugrande, R.,de, Text, Discourse and Process, Ablex, Norwood, N.J., 1980.
3. Chester, D.L., Using HCPRVR, Dept. of Comp. Sci.(mss.), University of Texas, Austin, 1979.
4. Chester, D.L., HCPRVR: A Logic Program Interpreter in LISP, Proc. AAAI, 1980, mss., Univ. of Texas, Dept. of Copm. Sci., Austin, 1980.
5. Jacobs, A.Roderick and Rosenbaum, S.Peter, English Transformational Grammar, Braisdell Publishing Co., Walthan, Massachusetts, 1968.
6. Satterthwait, "Sentence-for-Sentence Translation: An Example.", Mechanical Translation and Computational Linguistics, vol. 8., No. 2, February 1965, 14-38.
7. Simmons, R.F. and Chester, D.L., Relating Sentences and Semantic Networks with Procedural Logic, CACM (to appear), Dept. of Comp. Sci., Univ. of Texas, Austin, 1980.
8. Tosh, Wayne, Syntactic Translation, Mouton & Co., The Hague, 1965.

VITA

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