Treatment of Tense and Aspect in Translation from Italian to Greek
- An Example of Treatment of Implicit Information in Knowledge-based Transfer MT -

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1 Introduction

Treatment of tense and aspect is one of the well-known difficulties in MT, since individual languages differ as to their temporal and aspectual systems and do not allow simple correspondence of verbal forms of two languages. An approach to time suitable for MT has been elaborated in the EUROTRA project (e.g. [van Eynde 1988]) which avoids a direct mapping of forms by:

- Providing a model for semantic interpretation of temporal information
- Taking into account aspectual properties of events and temporal modifiers in order to choose the correct interpretations

However, though this approach provides a model for semantics of temporal expressions, it provides only partial solutions to the problem of interpretation. Natural language is inherently under-determined and in many cases information necessary for determining interpretations in terms of the proposed model is missing in SL sentences. A purely linguistic, sentence-based approach to translation simply cannot solve many of the problems caused by ambiguities in temporal interpretation.

The distinction between multiple occurrence and single occurrence interpretations, for example, leads to translations with different morphological markings in Greek, while the distinction is often implicit in many languages.

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Based on purely linguistic cues, it is usually difficult to choose the correct ones among possible interpretations and hence produce the correct translations.

Also, this approach requires the SL analysis to disambiguate all possible distinctions of temporal relations, regardless of whether the distinctions lead to different translations or not. Due to the highly ambiguous nature of this level of interpretation, the approach easily results in combinatorial proliferation of possible interpretations.

In this paper, we propose a framework in which temporal interpretation takes place during transfer, and show how the framework can feed the result of temporal interpretation of linguistic expressions in terms of extra-linguistic knowledge, general temporal knowledge, etc. into the main process of translation. Though our framework assumes a semantic model similar to that of van Eynde, the framework requires neither that interpretation results be represented explicitly nor that translation be performed via this level of representation. Inference is invoked during transfer to infer implicit information necessary for choosing the correct target translations.

Compared with van Eynde's proposal, knowledge-based Interlingua MT such as CMU's KBMT [Nirenburg 1987], and the conventional type of transfer MT systems, our framework has the following advantages :

- Clear separation of linguistic knowledge for translation (definition of translation equivalence pairs) from extra-linguistic knowledge in terms of which linguistic forms are to be interpreted
- Translation oriented, language-pair dependent invocation of inference

Among other problems, we focus in this paper on the distinction of multiple vs single occurrence interpretations in translation from Italian to Greek, and show how our MT framework treats translation problems involving knowledge-based interpretation.

2 Multiple Occurrences of Events and Translation

2.1 Problems in Italian-to-Greek Translation

The following cases can be distinguished with respect to event occurrences:

- single occurrence (corresponding to the adverbial 'once')
- cardinal quantification (corresponding to the adverbials 'twice', 'three hundred times', etc.)

- definite frequency ('twice a week', 'every day')
- indefinite frequency ('sometimes', 'always', 'rarely')
- habituality

Some languages, for example Greek, explicitly distinguish single occurrence and cardinal quantification of events from definite/indefinite frequency of events and habituality. The former require *perfective* morphological aspect in Greek, while the latter are expressed by *imperfective* aspect.

O Iannis *ksipnise* noris (mia fora/dio fores)
(John woke up early (once/twice))
0 Iannis *ksipnuse* noris (kathe mera/sihna/taktika)
(John woke up early (every day/often/regularly))

On the other hand, Romance languages like Italian show a similar distinction only in the past indicative tense. In all the other moods and tenses, frequency and habituality can either be expressed by means of adverbials or be totally implicit in a sentence.

Giovanni si sveglierà presto (una volta/due volte/ogni giorno/spesso /abitualmente)
- John will wake up early (once/twice/every day/often/regularly)

Furthermore, some frequency adverbials in Italian are used together with *perfective* aspect. For example, unlike Greek, *every day* in Italian requires in some cases the perfective [1].

Giovanni si è svegliato presto ogni giorno per un anno
John has woken up early every day for a year

As a consequence, in translation from Italian into Greek, single or numerically definite occurrences of events and numerically indefinite occurrences of events (i.e. frequency and habituality) must be distinguished. The most problematic distinction is the one between single and multiple occurrences, since cardinal quantification is almost always marked explicitly by cardinal quantifiers.

[1] In fact *every day* in Italian can occur with both aspects. In the specific example in the above the imperfective would not be correct, but with a temporal location instead of a duration specification, both forms would be equally acceptable in Italian.

Giovanni si sveglierà presto
(John will wake up early)

— O Iannis tha *ksipnai* nwris (mult.occ.)
— O Iannis tha *ksipnisi* nwris (sing.occ.)

Note that the distinction is crucial in translation to Greek, because of the nature of Greek. Although translation to Japanese, which has a quite different system of tense and aspect from that of Italian, generally requires a more explicit interpretation of temporal relations, it does not require the distinction we discuss here, which is not explicit in Japanese, either. On the other hand, translation between a pair of languages whose tense and aspect systems are similar to each other (like Italian and Spanish or Korean and Japanese) may require less explicit interpretation, if not none.

In short, translation of a different language pair requires a different degree of explicitness of interpretation as to different aspects of temporal properties/relations of events. Therefore, our framework invokes knowledge-based processing during transfer to perform disambiguation of SL interpretation as to the aspects required by the TL, to the degree of granularity determined by the TL.

2.2 Treatment in Linguistics-based Transfer MT

While interpretation-based or understanding-based MT frameworks tend to force the SL analysis to *interpret* source texts to the furthest extent regardless of the goal of the current task, i.e. translation between two particular languages, conventional linguistics-based transfer systems avoid introduction of interpretation or understanding processes into MT systems. They try to use linguistic cues inside sentences extensively, because they are the only cues available to those systems.

In some cases, existence of explicit temporal adverbials such as once, *often, every day,* etc. helps them to choose proper aspect forms in the TL. However, in most cases, the correct temporal interpretations and hence the correct choice of aspect need extra-linguistic knowledge about events described by sentences. For example, interpretation often depends on extra-linguistic knowledge such as whether the described event is normally performed by an individual or by a group of individuals, how long the described action normally takes, etc. (See Section 6).

Although some of such extra-linguistic knowledge about events or actions can be coded as a semantic classification of verbs and used as conditions in transfer rules, such a classification cannot be justified by purely linguistic criteria, but tend to be an extra-linguistic classification of events which linguistic forms describe and which, in its nature, is subject domain dependent.

Direct reference to such classifications in transfer rules destroys the modularity of knowledge representation between bilingual translation knowledge and domain-specific extra-linguistic knowledge, and as a result, the reusability of existing bilingual knowledge becomes very difficult, if not impossible.

Furthermore, as we see in **Section 6,** not only verbs but also the nouns associated with them determine the nature of described events. To specify such correlation between several constituents directly in transfer rules makes the description of bilingual knowledge unnecessarily complex. In short, conventional transfer-based MT systems tend to treat the conditions based on extra-linguistic knowledge about the described world in the same way as they treat linguistic conditions. It seems natural to treat two different sorts of conditions by separate components and combine them in the transfer process.

After a description of the problem of multiple occurrence interpretation in **Section 3**, we propose an MT model in **Section 4** which augments the conventional transfer MT model with a separate knowledge-based processing module, and then discuss in the following sections how our MT model actually treats translation problems involving temporal interpretation.

3 Semantics of Multiple Occurrences of Events

From the semantic point of view, multiple occurrences of events can be defined in terms of mutual relationships among events, participants and temporal locations. Events are temporally located, i.e. they are interpreted with respect to temporal intervals or locations ([Stirling 1985], [van Eynde 1987]: see also [Newton 1979], [Mourelatos 1978] for slightly different treatments) which may be explicitly expressed by temporal modifiers and/or temporal subordinate clauses, or completely implicit, having to be determined outside sentences by discourse or extra-linguistic factors:

> John went to the library *yesterday*
> John went to the library *when it was raining*
> *Yesterday* it was raining. John went to the library.
> John went to the library.

In their turn temporal locations can be quantified, and quantification over temporal locations gives rise to multiple occurrence interpretation of events.

> John goes to the library every afternoon

Like quantification over temporal locations, quantification over participants also gives rise to multiple occurrence interpretation, but is often ambiguous between collective (single-occurrence) and distributive (multiple-occurrence) interpretations with respect to temporal location [Stirling 1985] [Krifka 1990].[2] For example, the sentence

> Gli studenti saranno esaminati in matematica il mese prossimo
> (The students will be examined in mathematics next month)

is ambiguous between these two readings. Depending on the reading, the sentence should be translated into one of the following sentences in Greek :

[Collective:Single Occurrence Interpretation] : All the students are going to be examined in a single session. - *Perfective*

> I fitites tha *eksetastun* sta mathimatika to epomeno mina.

[Distributive: Multiple Occurrence Interpretation]: Different students are going to be examined in different sessions. - *Imperfective*

> I fitites tha *eksetazonte* sta mathimatika to epomeno mina.

Multiple occurrences of events could be graphically represented as follows [van Eynde 1987].

```
                 E
         ___________________________
         !__I__I__I__I__I__I__I__I__I!
         !  !  !  !  !  !  !  !  !  !
         !  e! e! e ! e! e! e! e! e! e!
    ----- *--*--*--*--*--*--*--*--* ---------------------------- >
         !___________________________!     time axis
```

Fig. 1

E represents the temporal location of an event (macro-event, [Timberlake 1982]) made up of all occurrences of repeated events of e (micro-events). The set of I represents the frequency specification, and the the set of e represents the temporal location of each of the repeated micro-events. Multiple occurrence does in fact correspond to quantification over the temporal locations. Quantification can be universal, as in the case of definite iteration:

[2] Krikfa uses multiple-object vs. multiple-event reading instead of collective vs. distributive reading.

Last year they played chess every week

or correspond to different types of quantifiers, as in the case of frequency adverbials (eg: always - UNIVERSAL, sometimes - EXISTENTIAL, seldom,rarely - FEW, often - MANY, usually - MOST, etc.) Habituality can be considered as a particular case of frequency, corresponding to the temporal quantifier MOST.

Distinguishing a single occurrence of an event from multiple occurrences of micro-events is not so easy for languages such as English, Italian and Japanese which lack explicit markings. In these languages, relevant linguistic cues are scattered in various types of constituents or absent inside single sentences. Even when they exist inside sentences, they are often ambiguous and their proper interpretation cannot be determined unless we refer to extra-linguistic knowledge.

The distributive/collective reading ambiguity, for example, lacks in most cases necessary cues for disambiguation. As for temporal locations, temporal adverbials inside sentences can only partially constrain the possible interpretations, i.e. it is not so straightforward to determine which event's temporal location (a macro-event or micro-event) is actually modified by them. Examples in Section 6 show that sentences linguistically ambiguous with respect to single vs. multiple occurrence reading can be interpreted correctly by referring to extra-linguistic world-knowledge associated with event types.

4 The MT model

The MT framework we adopt basically follows the one described in [Tsujii 1986], [Tsujii 1992] and [Phillips 1992]. The framework has been subsequently revised in order to treat interaction among rules [Kinoshita 1992] and also to cope with the requirements of the treatment of tense and aspect we discuss in this paper. In particular, the logical form representation has been augmented to represent the distinction between macro- and micro-events explicitly.

The MT model can be graphically represented by the scheme in Fig. 2: The crucial point in this scheme is that, while knowledge-based processing is invoked during transfer, translation is performed through linguistic forms of the two languages, not via knowledge-based interlingua. That is, transfer is basically performed by referring to a set of translation equivalence pairs (bilingual translation knowledge) defined between logical-form representations of the source (S-LF) and of the target (T-LF).

```
                    __________________
                    !   Knowledge-Base   !
                    !__________________!
                              !
                 _______________________
                 !   Inference Component   !
                 !______________________!
[KNOWLEDGE-BASED              A
 PROCESS]                     !
                              !
______________________________________________________________________
[TRANSLATION-PROCESS]         !
                              !
                              V
      ________       _________        __________
     ! Analysis !====> ! Transfer !=====>!  Generation !
     !________!       !_______!       !_________!
                              !
                 _______________________
                 !   Bi-Lingual Knowledge!
                 !______________________!
```

Fig.2 Transfer with Knowledge-based Components

Since different languages make explicit different aspects of situations (or objects, events, etc.) which they describe, translation pairs are defined between LFs which may differ in their explicitness of some aspects of meanings. These differences are represented as conditions in the definition of translation pairs. During transfer from a less explicit language to a more explicit one, these conditions are evaluated by invoking knowledge-based processing [3], and only translation pairs with satisfied conditions are chosen to compose the LF of the target. As a result, two texts of SL and TL may have different degrees of explicitness in some aspects of meaning.

Logical forms of texts are unordered sets of terms (atomic formulae) which consist of indices, properties and relations. For example,

john(j), see(e), mary(m), subject(j,e), object(m,e)

[3] In this paper, we assume a knowledge-based component which determines proper temporal interpretations. However, in practical application environments, one could replace this component with human experts who interact with MT systems or a component which uses heuristic cues in order to reply to the translation process.

is the LF of the sentence *John sees Mary*. Indices such as j, e, and m correspond to discourse entities, while properties (*john*, *see* and *mary)* and relations *(subject* and *object)* correspond either to lexical items in sentences or relations between indices[4]. Intuitively, each index is a unique entity described by a fragment of expressions in a sentence. For example, **j** is an object-entity described by *john* in English and **e** is an event-entity which belongs to a class of events that can be described by *see* in English.

The simplest form of a translation pair (or a transfer rule) is :

ig([giovanni(J)], [iannis(J)]).

which reads as "an object-entity described by *giovanni* in Italian can be described by *iannis* in Greek".[5] This simplest form can be constrained by conditions of various types:

[1] Linguistic Context: One can check whether specified terms exist in LF of the source text or the target text. The conditions 'in-source' and 'in-target' ensure respectively that the transfer rule applies only when LF of the source or the target contains the specified term (or set of terms). For example,

ig([aspect(E,imperfective), cond([in(tense(E,simul))])],
[aspect(E,imperfective)])

This rule establishes a translation pair of terms representing the aspects in the S-LF and T-LF (both imperfective)[6], under the condition that LF of the source text contains a term with a specific tense value (simultaneous).

[2] Shift: Changes in Indices: A shift condition holds between S-LF and T-LF when an index of the source is substituted in all its instances by another index in the target. This handles cases of complex transfer like head switching [Lindop 1991], and can also be used recursively in case of combined syntactic changes [Sun 1992]. For example,

ig([prendere(E), decisione(D), obj(E,D), cond([shift(2,D,E)])],
[(apofasizo(E)]).

[4] Though we omit the details, grammatical properties such as Number, Voice, etc. are also represented as properties of indices.

[5] Indices play a dual role in our framework as linguistic objects and also as extra-linguistic entities, i.e. entities which are described by linguistic objects. This duality is the key for interaction between the transfer which is basically a linguistic operation and the knowledge-based interpretation

[6] Though the terms in S-LF and T-LF are the same in this example, they have completely independent semantics. That is, the term in S-LF only means that an event E is described by a sentence with imperfective aspect in Italian.

In this rule, the translation pair between the support verb construction *prendere una decisione*(to make a decision) and the verb *apofasizo* (to decide) is defined, and the shift condition shows that the index for the noun *decisione* in the Italian LF is stated to be lexically included in the index for the verb *apofasizo* and disappear in the Greek LF.

[3] Conditions which Invoke Knowledge-based Processing: Conditions can be a set of terms which have to be proved by the knowledge base. Reasoning is performed on the basis of the content of the knowledge-base and LF of the source. A special functor 'pred' is used which indicates that the translation pair is valid only if the formulae (or set of formula) specified in the condition is proved to be true.

```
ig([aspect(E,perfective),
cond([pred(mult-occurrence(E)), shift(1,E1,E)])],
[set(E,E1), aspect(E1,imperfective)])
```

This rule establishes equivalence between perfective aspect in Italian and imperfective aspect of a macro-event in Greek. The rule is applied only when the event, E, whose aspectual value is in question is proved to have multiple occurrence interpretation. The shift condition also ensures that the tense and aspect values are assigned in the Greek LF to the explicit macro-event, E1.

5 The Logical Form

The format of LF representing source and target texts has been extended from the original version of [Phillips 1992] in order to accomodate temporal interpretation. In the following, we enumerate the extensions relevant to the current discussion. Though notations are introduced to express some aspects of meanings more explicitly than intermediate representations in conventional transfer MT systems normally allow, one should note that this does not imply that all ambiguities involving interpretation can or have to be represented at this level of representation. Instead, most interpretation ambiguities, for example scopes of quantifiers or collective vs distributive readings, remain implicit at this level. Disambiguation takes place during transfer, if it is necessary. However, it is important that LFs of the source and the target have a sufficient expressive power to represent explicitly information conveyed by linguistic forms which is relevant to knowledge-based processing i.e. temporal interpretation.

[A] Sets of Entities and Quantification: As noted in [Webber 1983], [Di Eugenio 1986], etc., sets of entities introduced by plural NPs behave as if they are single entities, and can be referred in succeeding context. Such plural referents are treated as independent entities and assigned separate indices in LF.[7]

the books: libro(b), set(b,b1)

The above shows that b1 is a plural referent whose member entities, b, belong to a class of objects which can be described by *libro* in Italian. While plural referents generally introduce scope ambiguities, i.e. collective vs distributive readings, LF of the source keeps the ambiguity implicit. For our purpose, however, it is important for plural referents and individual members to be assigned indices separately.

read the books: libro(b), set(b,b1), leggere(l), obj(l,b1)
(book - libro, read - leggere)

A set notation allows its members to be quantified such as :

all the books: libro(b), tutti(b), set(b,b1)
(all - tutti)

As we see in [B], temporal locations are also assigned indices as normal discourse entities and frequency adverbials are treated as quantifiers over them.

every afternoon: pomeriggio(p), ogni(p), set(p,p1)
(every - ogni, afternoon - pomeriggio)

A macro-event which consists of micro-events is also treated as a set :

wake up (macro-event): svegliarsi(s), set(s,s1)
(wake up - svegliarsi)

[B] Temporal Entities and their Relations to Events: LF must include relations among temporal locations of separate events, and be able to represent quantification over temporal locations, frequency expressions and temporal subclauses, in order to represent the distinction between macro- and

[7] For the ease of readers, we show English translations of original Italian phrases as in the above examples and also in the following.One sees original lexical items of Italian used as predicates in LF like *libro - book* in English. We use English predicate names like *set, object, tense,* etc. to indicate that they are not lexical items of the source. We ignore in the examples some of the details of LF which are irrelevant to the current discussion. The distinction of specific vs generic reference, for example, is ignored in the above example.

micro-events. Like the other normal kinds of entities such as *libro* (book), temporal entities are also treated as independent discourse entities and assigned their own indices. This treatment seems natural since many temporal locations are expressed by Nouns or NPs and can be referred to in succeeding context by definite NPs or some other referring expressions like *then.*

While we do not discuss in this paper the nature and structure of time, we assume the following in our model of time :

- temporal entities (i.e. temporal locations) in our representation correspond to intervals in the time axis
- intervals can be measured according to time units
- a set of relations like interval relations of [Allen 1983] can be defined between intervals on the time axis, and therefore, between temporal entities

Relations between temporal entities and events are also represented by predicates. However, unlike other predicates like *subj, obj* which relate entities with event-entities, these predicates are language-independent predicates, i.e. predicates in the interpretation domain, which specify temporal relations between events and temporal locations across different languages. The following is a list of the basic predicates which relate event-entities with temporal-entities.

1 **event-int**: Events have their own running times, ie. their occurrences occupy particular time intervals. Therefore, each event occurrence is associated with a particular temporal entity by predicate event-int.

2 **duration**: The running time of an event can be measured and therefore, an event is associated with time measure units by predicate duration.

3 [**during,before,after,at**]:An event can be located vaguely on the time axis by specifying a temporal interval in terms of which the running time of the event is implicitly constrained. There are the following four predicates:

> **during**: the running time of an event is included in the specified temporal entity.
> **before**: the running time of an event precedes the specified temporal entity.
> **after**: the running time of an event follows the specified temporal entity.
> **at**: the running time of an event coincides with the specified temporal entity whose duration is 0.

Among these predicates, event-int is the fundamental one which associates an event with its running time. However, the running time of an event is usually not expressed explicitly in natural language texts. Temporal entities which appear explicitly in texts are the entities to be related with events through the predicates of the third category, i.e. during, before, etc. The only exceptions are temporal subordinate clauses in which the running times of the events expressed by the subordinate clauses are used to specify the temporal location of the main clauses, such as :

go when it rains:	piovere(e1), event-int(t,e1),
(rain - poivere,	andare(e2), during(t,e2)
go - andare)	

In this example, the running time **t** of **e1** (the event expressed by the subordinate clause) is used to specify the temporal location of the main clause, **e2**. Note also that an event can be located in time with a variable degree of precision and that multiple temporal entities can appear, all of which constrain the running time of the same event. That is, an event can be located with respect to a subinterval of a given interval which is in its turn a subinterval of a larger interval, etc. In such cases, we associate all temporal entities with the same event so that, unlike grammatical functions, the temporal predicates referring to temporal location are not necessarily unique for a single event.

The following are some examples of logical forms of events with temporal entities:

- hour indication

  arrive at 8 o'clock: otto(o), arrivare(e) at(o,e)
  (arrive - arrivare)

- interval indication

  arrive yesterday: arrivare(e), ieri(i), during(i,e)
  (yesterday - ieri)

- duration indication

  sleep for one hour: dormire(e), ora(o), duration(o,e)
  (sleep - dormire)

- temporal quantifiers

  read every day:leggere(e), giorno(g), ogni(g), set(g,gl), during(gl,e)
  (read - leggere, every - ogni, day - giorno)

Frequency adverbs like *often* introduce a set of (unspecified) temporal locations over which corresponding quantifiers are applied.

- frequency adverbials

  go often: spesso(t), set(t,t1), andare(e), during(t1,e)
  (often - spesso, go - andare)

The following are examples which contain frequency adverbials as well as temporal locations.

(l)Giovanni legge sempre il giornale nel pomeriggio
(John always reads the newspaper in the afternoon)

giovanni(j), leggere(e1), giornale(g), subj(e1,j), obj(e1, g), pomeriggio(p), sempre(p), set(p,pl), during(pl,e1)

(2)Giovanni legge sempre il giornale quando piove
(John always reads the newspaper when it rains)

piovere(e1), event-int(t, e1), sempre(t), set(t,t1), giovanni(j), leggere(e2), giornale(g), subj(e2,j), obj(e2,g), during(t1,e2)

[C] Tense and Aspect: Temporal and aspectual meanings expressed by verbal morphology are assigned to events. The semantic notions are adopted from [van Eynde 1987].

LFs are however ambiguous with respect to aspect when verbal forms do not explicitly mark them, i.e. tenses which don't express aspectual distinctions do not introduce aspectual information in LF. Here again, we follow the principle that ambiguities related with interpretation are kept implicit and are explicitly captured during transfer, if the target requires disambiguation.

The following are the logical forms of some of the Italian examples used in the following section:

L'anno prossimo Giovanni si laureerà
(Next year John will graduate)

anno(an), prossimo(an), giovanni(j),
laurearsi(e), subj(e,j),
during(an,e), tense(e, post)

Lunedì prossimo Giovanni si svegliarà presto
(Next Monday John will wake up early)

lunedi(lu), prossimo(lu), giovanni(j),
svegliarsi(e), presto(e),
subj(e,j), during(lu,e), tense(e,post)

6 Identification of Implicit Macro-Events

6.1 Observations

As the previous section shows, imperfective aspect in Greek is chosen when the number of occurrences of described events is indefinite i.e. indefinitely quantified. On the other hand, perfective aspect is chosen for both single or cardinally quantified events. As a consequence, to ensure correct translation, rules for identifying and individuating macro-events are crucial.

However, there are many cases in which no linguistic cues exist to identify macro-events or in which the same linguistic constructions should be interpreted differently, depending on extra-linguistic properties of described events :

1. Next year John will graduate
2. Next week John will graduate

3. Next Monday John will wake up early
4. Next month John will wake up early (everyday)

5. Next year the Commission will celebrate the anniversary
6. Next week the Commission will celebrate the anniversary
7. In the next decade the Commission will celebrate the anniversary

8. John will wake up early for one day
9. John will wake up early for one month

10. Next week John will go out on Monday

11. Next month John will go out on Monday(s)

None of these examples contain any temporal quantifier or frequency indication. However, even without taking into account preceding or following context, any reader is able to interpret ex. 1), 2), 3), 5), 6), 8) and 10) as referring to a single event and ex. 4), 7), 9) and 11) as referring to multiple events.

In the case of ex. 1) and 2), what excludes a multiple occurrence interpretation is the fact that one is likely to get a degree only once in a lifetime (semelfactivity). The temporal context during which such an event is located (next year vs. next week) plays no role in this case. Events like 'graduating', 'getting married', etc., cannot occur in a multiple-event context unless multiple and generic participants are involved.

In the case of ex. 3) and 4), on the contrary, different pieces of knowledge are relevant: waking up is a typical habitual event, and its typical frequency is (at least) once a day. As a consequence, the temporal context of sentence 3) (Monday, i.e. a temporal location of one-day length) allows only a single-event interpretation, while the temporal context of sentence 4) allows only a multiple-event interpretation. The same can be said about ex. 5) and 6) vs. 7), but since the typical frequency of anniversaries is annual, the single-event interpretation occurs with temporal contexts of length shorter or equivalent to one year, while the multiple-event interpretation can occur only with larger temporal contexts.

Ex. 8) and 9) show that duration specifications contribute relevant information exactly in the same way as temporal locations. Finally, examples 10) and 11) show the relevance of deictic vs. cyclic interpretation of temporal locations, which depends on calendar knowledge. Deictic temporal locations correspond to single domain entities, while cyclic may correspond to 'set' domain entities according to the general temporal context.

6.2 Types of Knowledge

From the above observations, some conclusions can be derived about the types of knowledge and the type of reasoning rules necessary to distinguish single from multiple event occurrences:

[A] Knowledge about Temporal Entities:

Temporal entities used in language reflect:

- **calendar** : a system of reference to time, i.e. of situating intervals on the time axis and naming them
- **time units** : a system for time measuring

The two aspects of time-related expressions are not independent. Expressions of time units are used in language also as expressions for locating time intervals. The calendar has its own hierarchical organization which is not an IS-A hierarchy but similar to a PART-WHOLE hierarchy, i.e. time is subdivided into intervals (of roughly equal length), which are in their turn subdivided into subintervals, etc. Also, named intervals are sometimes ordered according to their relative position within larger intervals, and their orderings are often cyclic.

With respect to multiple occurrence of events, the temporal knowledge base has to provide the means for comparing the expected frequency of an event with its interval location or its duration. Therefore, it must reflect the following relations:

- relations between intervals in the calendar and between time measure units:

  -- include holds between an interval and its direct subintervals

  -- **in** holds between an interval and all its direct or indirect subintervals

  -- coincide holds between intervals of the same type

- relations between interval names and interval types (Monday is a day, etc.).

Furthermore, it is necessary to provide the necessary means for computing location intervals when they are given implicitly in the input (i.e. if an event takes place between Monday and Friday then its location interval is of a given number of days). In some cases however the information provided by the sentence may not be sufficient to precisely characterize the location interval, or there may be no information at all.

Here are some examples of the predicates used in the knowledge base:

a include(X,Y) :- in(X,Y).

b include(X,Y) :- in(X,Z), include(Z,Y).

c in(X,Y) :- anno(X), mese(Y).

d in(X,Y) :- mese(X), settimana(Y).
etc.

Though we use rather common nouns such as *month, year,* etc. as examples for the sake of explanation, we assume that such expressions or words which denote temporal locations and on which calendar relationships such as the above are defined would depend on specific application domains. While such temporal locations specific to application domains need additional axioms to specify their mutual relationships, the same set of basic predicates such as *include, in,* etc. and the axioms of these basic predicates can be shared by different application domains.

[B] Knowledge about Events:

Two types of time-related knowledge about events are relevant:

- **Typical duration**: events can be assigned an approximate indication of their typical length in time, which can be represented directly as a measure or as a scale (an appropriate time unit). Typical duration of events is needed in order to explicitly measure the location interval of some event which is provided in the input in relation to the event in question. Also, duration can be determined by the presence and nature of some participants *(walk* may have different typical durations for *walk to work* or *walk one mile).*

- **Typical frequency**: typical frequency of events is related to the possibility of multiple event occurrence with respect to given participants. Three classes of events can be distinguished:

  1 Semelfactive events typically have a unique occurrence for a specified tuple of participants, i.e. they can undergo multiple occurrence only assuming different participants for each event occurrence (e.g. to get a degree, to get married, to die, etc.).

  2 Habitual events can undergo multiple occurrence with respect to a specified tuple of participants, and their occurrence follows reasonably homogenous patterns which makes it possible to specify a typical frequency (e.g. to have lunch, to wake up, etc.). The typical frequency is expressed by a time measure (i.e. for the Olympic games, four years). Events can be habitual to different degrees. For example, some types of activities can be performed in an habitual or an occasional way (e.g. playing tennis, playing chess etc.). With respect to these events, as a consequence, typical frequency represents the norm for the event to be habitual (e.g. playing tennis on a weekly basis).

  3 Indefinite frequency events are those for which multiple occurrence depends on specific tuples of participants and no 'habituality norm' can be identified (e.g. to walk).

  The distinction between habituality and non-habituality in many cases depends on the type of the participants. Participants can in their turn be habitual events, and determine the habituality of the event they participate in *(celebrate the anniversary, go to the football match).* Also, participants can bear various types of relations to other events and therefore affect the frequency of the event they participate in. E.g. *go to church* or *walk to one's office* are habitual events because of the habitual events which typically occur in the places involved.

The following are some examples of predicates related to knowledge about events:

habitual-activity(E) :- svegliarsi(E).
frequency(E,giorno,l) :- svegliarsi(E).
single-occurrence(E) :- laurearsi(E).
etc..

[C] Rules for detecting multiple-event occurrence:

In transfer, rules assigning aspect will contain knowledge base conditions. However, predicates used for specifying transfer conditions may be dependent on individual pairs of languages. The predicate multi-occurrence, for example, is used in a transfer rule for Italian and Greek, but this predicate may not play a crucial role in translation between Italian and Japanese. Different pairs of languages may need different set of interface predicates like *multi-occurrence.*

The following rule means that, if a multiple-event occurrence is proved by the knowledge base, then a macro-event is introduced in the T-LF, imperfective aspect is assigned to it and all relevant properties and relations are shifted (tense, etc.).

```
ig([aspect(E,perfective), cond(pred(multi-occurrence(E))],
     shift(1,E1,E)!)!,
    [set(E,E1), aspect(E1,imperfective)] ).
```

The following criteria are used to formulate appropriate rules for multiple-event detection:

1 For events whose typical frequency can be specified, multiple occurrence depends on the relation of the typical frequency with the temporal locations or the duration. Multiple occurrence exists when the typical frequency is a subinterval of one of the temporal locations, or of the duration (the temporal location or the duration include the typical frequency interval). Accordingly, temporal locations which include the typical frequency interval refer to the macro-event, and those which coincide or are included in it refer to the micro-event. Since the number of temporal locations specified for an event can be variable, it is necessary in rules to take into account the complete temporal context of an event (the whole set of temporal location specifications), so that all of them are compared with the typical frequency.

2 For semelfactive events, multiple occurrence is excluded, independently from temporal information, in case of single participants, and occurs in case of multiple generic participants.

3 For events which admit multiple occurrence but whose typical frequency cannot be determined or inferred, multiple occurrence can be detected by taking into account typical duration with respect to specified duration (e.g. go for a walk for one year). Also, it is possible to detect on the basis of typical duration the impossibility of multiple occurrence in a given temporal context (e.g. go for a walk between nine and ten today).

The following is an example of a rule:

```
mult-occurrence(E)  :- habitual-activity(E),
                       temp-context(L),
                       length(L,1),
                       during(T,E),
                       include-freq(T).
```

If multiple occurrence cannot be proved, then single occurrence is assumed and perfective aspect is assigned to the event in the T-LF.

Temporal locations on the other hand are translated by their own specific rules, which also include knowledge-base conditions of the same type. In case of multiple occurrence, temporal locations must in fact be assigned to the macro- or to the micro-event according to their inclusion or coincidence relationships to the assumed frequency interval of the event. Since both rules dealing with aspect and rules dealing with temporal locations can introduce macro-events, macro-event creation is subject to 'in-target' conditions to ensure consistency and macro-event uniqueness.

7 Discussion and Conclusions

We show in this paper that the framework of transfer-based MT can treat problems related with implicit information by invoking knowledge-based processing during transfer. As we discussed, the framework has the following advantages over interlingua-based MT and the conventional transfer approach.

[1] **Clear separation of bilingual knowledge and domain-specific extra-linguistic knowledge** : While bilingual knowledge is stated in a fairly general form specifying under what conditions certain linguistic forms of the source can be transferred to which linguistic forms of the target, the conditions are evaluated by referring to knowledge about specific domains.

That is, a translation pair only states that the pair is valid when, for example, the described event is proved to occur repeatedly (multiple occurrence). The proof of *multiple-occurrence* is performed by a separate component which refers to extra-linguistic knowledge about individual events. Because extra-linguistic knowledge about individual events may be highly dependent on specific subject domains, this modularity of the two components is highly desirable for the reusability of knowledge as well as systematic development of MT systems.

[2] **Disambiguation dependent on target languages**: The framework requires neither all possible temporal interpretations to be generated nor to be represented in a language-independent way. This prevents meaningless proliferation of interpretations from being generated. The approach invokes knowledge-based processings only as they are necessary for translation.

In this paper, we have taken a rather conservative approach to MT. That is, we assume that knowledge about individual events and temporal locations is organized around predicates derived from lexical items of individual languages. This allows, for example, the events described by *read* in English and *leggere* to be different and therefore have different implications in knowledge-based processing. The same is the case for the temporal locations denoted by *year* and *anno*.

This may, however, lead to a vast duplication of essentially the same extra-linguistic knowledge in the two languages. It may be desirable in some cases to use language-independent predicates, not only for the basic predicates such as *set, during, event-int* but also for predicates of individual events, temporal locations and frequency adverbials. This makes our approach closer to the interlingual or knowledge-based MT. However, even if we use language-independent predicates to specify extra-linguistic knowledge, the transfer framework can remain unchanged. We can map predicates derived from lexical items to language-independent predicates only to prove knowledge-based conditions, while the main process of translation is carried out based on bilingual knowledge.

While we show in this paper only a small part of temporal knowledge and axioms concerning temporal locations, the knowledge base at present is comprehensive enough for translation from Italian to Greek.

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