Keynote address:

Annotating clinical narratives with SNOMED CT

Aspects of Reliability and Semantic Interoperability
April 22-25, 2002; Toulouse, France

Colocated with AIPS'02, with several associated workshops.

Sponsored by KR, Inc.

The Eighth International Conference on Principles of Knowledge Representation and Reasoning (KR2002) will be held in Toulouse, France from 22 to 25 April 2002. KR2002 will be held in conjunction with AIPS'02. Explicit representations of knowledge manipulated by inference algorithms provide an important foundation for much work in Artificial Intelligence, including natural language dialogue systems, high level vision, robotics and other knowledge-based systems. The KR conferences have established themselves as the leading forum for timely, in-depth presentation of progress in the theory and principles underlying the representation and computational manipulation of knowledge. The traditional very high standard of papers will be maintained at KR2002.

Call for Papers

Submission deadline: 11:59pm, Hawaii Time, November 1, 2001

Information for Authors

Authors should consult http://www.kr.org/kr/k02/krr02Instructions.pdf for instructions on how to format their accepted papers.

Accepted Papers

A list of accepted papers is available.

Associated Workshops

KR2002 will have the following associated workshops:
- the 2002 International Workshop on Descriptive Logics (DL2002), which will be held April 19 - 21
- the Ninth International Workshop on Knowledge Representation meets Databases (KRDB-2002), which will be held April 21
- the Ninth International Workshop on Non-Monotonic Reasoning (NMR2002), which will be held April 19 - 21
- the Workshop on Formal Ontologies - Knowledge Representation and Intelligence Systems for the World Wide Web, which will be held April 19 - 20

KR2002 Home Page
Typical information engineering workflow
Typical information engineering workflow

Data Acquisition -> Data -> Representation

Reasoning A -> Result A
Reasoning B -> Result B
Typical information engineering workflow

Data Acquisition → Data

Data → Representation A → Reasoning → Result A

Data → Representation B → Reasoning → Result B
Typical information engineering workflow

Data Acquisition

Data

Representation A
- Reasoning
- Result A

Representation B
- Reasoning
- Result B

reliability

validity
Focus on data acquisition for information engineering.
Data reliability $\rightarrow$ Data interoperability
Data reliability $\rightarrow$ Data interoperability
Focus of the talk

- Analysis of coded extracts from clinical texts
- Inter-annotator agreement (reliability)
- Reasons for inter-annotator disagreement
- Discussion: how to improve agreement

Assumption:
- better data reliability
  -> better semantic interoperability of clinical data
Annotating clinical narratives with SNOMED CT
Annotating clinical narratives with SNOMED CT

**Coding**

- Observation
- reality observed → standardized representation

**Vocabularies**

- Resektat nach Whipple: Ein noch nicht eröffnetes Resektat, bestehend aus einem distalen Magen mit einer kleinen Kurvaturlänge von 9,5 cm und einer großen Kurvaturlänge von 13,5 cm, sowie einem duodenalen Anteil von 14 cm Länge. 2 cm aboral des Pylorus zeigt die Dünndarmwandung eine sanduhrartige...

**Annotation**

- Observation, interpretation
- intermediate representation

- symbols → standardized representation
Annotating clinical narratives with **SNOMED CT**

- **Huge clinical reference terminology**
- **eHealth standard, maintained by transnational SDO**
- **~300,000 "concepts" preferred terms and synonyms in several languages**
- **SNOMED CT representable as OWL EL**
- **(quasi-) ontological definitional and qualifying axioms**
- **Multiple hierarchies**
- **Covers disorders, procedures, body parts, substances, devices, organisms, qualities...**
Resektat nach Whipple*: Ein noch nicht eröffnetes Resektat, bestehend aus einem distalen Magen mit einer kleinen Kurvaturlänge von 9,5 cm und einer großen Kurvaturlänge von 13,5 cm, sowie einem duodenalen Anteil von 14 cm Länge. 2 cm aboral des Pylorus zeigt die Dünndarmwandung eine sanduhrartige Stenose. Im Magen- und Duodenallumen reichlich zähflüssiger Schleim, sanguinolent.

Best text span to annotate? Naïve or analytic annotation?

SNOMED CT
- Ill-defined concepts
- Similar concepts
- Pre-coordination vs. post-coordination
- Complex annotations (> 1 concept / term)

Ontology
- classes
- relations
- logical constructors
- axioms

Terminology
- concepts
- preferred terms
- synonyms
- definitions

Human language
- words, multiword terms
- syntactic structures
- relations at various levels

Clinical language
- Compact
- Paragrammatical
- Context-dependent

map
### Examples

<table>
<thead>
<tr>
<th>Clinical text</th>
<th>SNOMED CT concepts (FSNs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;... the duodenum. The mucosa is...&quot;</td>
<td>'Duodenal structure (body structure)'</td>
</tr>
<tr>
<td></td>
<td>'Mucous membrane structure (body structure)'</td>
</tr>
<tr>
<td></td>
<td>'Duodenal mucous membrane structure (body structure)'</td>
</tr>
<tr>
<td>&quot;...Hemorrhagic shock after RTA...&quot;</td>
<td>'Traffic accident on public road (event)'</td>
</tr>
<tr>
<td></td>
<td>'Traffic accident on public road (event)', 'Renal tubular acidosis (disorder)'</td>
</tr>
<tr>
<td></td>
<td>'Traffic accident on public road (event)' or 'Renal tubular acidosis (disorder)'</td>
</tr>
<tr>
<td>&quot;...travel history of suspected dengue...&quot;</td>
<td>'Suspected dengue (situation)'</td>
</tr>
<tr>
<td></td>
<td>'Suspected (qualifier value)'</td>
</tr>
<tr>
<td></td>
<td>'Dengue (disorder)'</td>
</tr>
</tbody>
</table>
Examples:

1. German coding guidelines for ICD and OPS, 171 pages
2. Using SNOMED CT in CDA models: 147 pages
3. CHEMDNER-patents: annotation of chemical entities in patent corpus: annotation manual 30 pages
4. CRAFT Concept Annotation guidelines: 47 pages
5. Gene Ontology Annotation conventions: 7 pages

Complex rule sets, requiring intensive training

Annotation experiments in ASSESS-CT
Annotation experiments in ASSESS-CT

- EU support action on the fitness of SNOMED CT as a EU core reference terminology

EU support action on the fitness of SNOMED CT as a EU core reference terminology

Domain experts annotate 60 samples of clinical documents with SNOMED CT

Annotation experiments in ASSESS-CT

- Nitroglycerin pump spray as required
  - 387404004;385074009;225761000
- Amantadine bds
  - 372763006;229799001
- Allopurinol 300 ½ tablet every other day (last dose on 20091130)
  - 387135004;385055001;225760004
- Mefenamic acid 500 mg up to 3x daily for pain in conjunction with simultaneous administration of a drug to protect the stomach e.g.
  - 387185008;258684004;229798009;22253000
  - 79970003;416118004;373517009;69695003
- Pantopozole 40mg.
  - 395821003;258684004
- Torasemide bds
  - 318034005;229799001
- Melperone 50 mg p.m.
  - 442519006;258684004;422133006

§ 7 Intact teeth are in the mouth.
- 11163003;245543004;123851003
- Fractures are visible on the medians of Mandible and Maxilla the fragments are dislocated.
  - 123735002
- Normal mucous membranes in mouth pharynx and on the larynx.
  - 17621005;33044003;71248005
- Hyoid and thyroid cartilage are intact.
  - 21387005;52940008;11163003
- Fragmental fractures of the two upper vertebrae of the cervical spine.
  - 13321001;207984009;207983003
- Otherwise the cervical spine is intact.
  - 122494005;11163003
- Oesophagus as well as
  - 262793000;282459005;261122009;123958008
EU support action on the fitness of SNOMED CT as a EU core reference terminology

Domain experts annotate 60 samples of clinical documents with SNOMED CT

1/3 of samples annotated twice

Support: Webinars, annotation guidelines
## Principal quantitative results (English)

<table>
<thead>
<tr>
<th></th>
<th>SNOMED CT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concept coverage [95% CI]</strong></td>
<td></td>
</tr>
<tr>
<td>Text annotations – English</td>
<td>.86 [.82-.88]</td>
</tr>
<tr>
<td><strong>Term coverage [95% CI]</strong></td>
<td></td>
</tr>
<tr>
<td>Text annotations – English</td>
<td>.68 [.64; .70]</td>
</tr>
<tr>
<td><strong>Inter annotator agreement</strong></td>
<td></td>
</tr>
<tr>
<td>Krippendorff's Alpha [95% CI]</td>
<td></td>
</tr>
<tr>
<td>Text annotations</td>
<td>.37 [.33-.41]</td>
</tr>
</tbody>
</table>

(similar results with alternative annotation task, using non-SNOMED UMLS extract)

Agreement map: SNOMED annotations

- green: agreement
- yellow: only annotated by one coder
- red: disagreement
- white: no annotations
Systematic error analysis
Systematic error analysis

- Creation of gold standard for SNOMED CT
  - 20 English text samples annotated twice → 208 NPs
  - Analysis of English SNOMED CT annotations by two additional terminology experts
  - Consensus finding, according to pre-established annotation guidelines
- Inspection, analysis and classification of text annotation disagreements
- Presentation of some disagreement cases for SNOMED CT
Reasons for disagreement
Human issues

- Lack of domain knowledge / carelessness

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;IV&quot;</td>
<td>'Structure of abductor hallucis muscle (body structure)'</td>
<td>'Abducens nerve structure (body structure)'</td>
<td>'Abducens nerve structure (body structure)'</td>
</tr>
</tbody>
</table>

- Retrieval error (synonym not recognised)

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Glibenclamide&quot;</td>
<td>'Glyburide (substance)'</td>
<td>—</td>
<td>'Glyburide (substance)'</td>
</tr>
</tbody>
</table>
Ontology issues (I)

- Logical polysemy ("dot categories")*

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Lymphoma''</td>
<td>'Malignant lymphoma (disorder)'</td>
<td>'Malignant lymphoma - category (morphologic abnormality)'</td>
<td>'Malignant lymphoma (disorder)'</td>
</tr>
</tbody>
</table>

### Incomplete definitions

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Motor: normal bulk and tone&quot;</td>
<td>'Skeletal muscle structure (body structure)'</td>
<td>'Muscle finding (finding)'</td>
<td>'Skeletal muscle normal (finding)'</td>
</tr>
<tr>
<td>'Normal (qualifier value)'</td>
<td></td>
<td>'Normal (qualifier value)'</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram showing skeletal muscle normal (finding) and finding site.]
**Ontological issues (II)**

- **Incomplete definitions**

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
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<tbody>
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<td>&quot;Motor: normal bulk and tone&quot;</td>
<td>'Skeletal muscle structure (body structure)'</td>
<td>'Muscle finding (finding)'</td>
<td>'Skeletal muscle normal (finding)'</td>
</tr>
<tr>
<td></td>
<td>'Normal (qualifier value)'</td>
<td>'Normal (qualifier value)'</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Former smoker&quot;</td>
<td>'In the past (qualifier value)'</td>
<td>'History of (contextual qualifier) (qualifier value)'</td>
<td>'Ex-smoker (finding)'</td>
</tr>
<tr>
<td></td>
<td>'Smoker (finding)'</td>
<td>'Smoker (finding)'</td>
<td></td>
</tr>
</tbody>
</table>
Ontological issues (III)

- Navigational concepts

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;palpebral fissure&quot;</td>
<td>Finding of measures of palpebral fissure (finding)</td>
<td>Structure of palpebral fissure (body structure)</td>
<td>Measure of palpebral fissure (observable entity)</td>
</tr>
</tbody>
</table>

- Fuzzy, undefined qualifiers

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Significant bleeding&quot;</td>
<td>'Significant (qualifier value)'</td>
<td>'Severe (severity modifier) (qualifier value)'</td>
<td>'Moderate (severity modifier) (qualifier value)'</td>
</tr>
<tr>
<td></td>
<td>'Bleeding (finding)'</td>
<td>'Bleeding (finding)'</td>
<td>'Bleeding (finding)'</td>
</tr>
</tbody>
</table>
## Interface term (synonym) issues

<table>
<thead>
<tr>
<th>Tokens</th>
<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Blood extravacation&quot;</td>
<td>'Blood (substance)'</td>
<td>'Hemorrhage (morphologic abnormality)'</td>
<td>'Hemorrhage (morphologic abnormality)'</td>
</tr>
<tr>
<td></td>
<td>'Extravasation (morphologic abnormality)'</td>
<td></td>
<td>&quot;extravasation of blood&quot;</td>
</tr>
</tbody>
</table>

**Hemorrhage**
- SCTID: 50960005
- 50960005 | Hemorrhage (morphologic abnormality) |
  - Hemorrhage
  - Extravasation of blood
  - Blood loss
  - Bleeding
  - Haemorrhage
  - Hemorrhage (morphologic abnormality)

No attributes
### Interface term (synonym) issues

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<th>Gold standard</th>
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<td>&quot;Blood extravasation&quot;</td>
<td>'Blood (substance)'</td>
<td>'Hemorrhage (morphologic abnormality)'</td>
<td>'Hemorrhage (morphologic abnormality)'</td>
</tr>
<tr>
<td></td>
<td>'Extravasation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(morphologic abnormality)'</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;extravasation of blood&quot;</td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>Annotator #1</th>
<th>Annotator #2</th>
<th>Gold standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;anxious&quot;</td>
<td>'Anxiety (finding)'</td>
<td>'Worried (finding)'</td>
<td>'Anxiety (finding)'</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&quot;anxious cognitions&quot;</td>
</tr>
</tbody>
</table>
Prevention and remediation of annotation disagreements
Prevention and remediation of annotation disagreements

- Rationales:
  - More principled SNOMED CT coding of EHR content
  - More principled binding of SNOMED CT codes to clinical models
  - Consistent manual annotations for training corpora and reference standards
  - Improvement of performance of NLP-based annotations
Preventive measures
Prevention: annotation processes

- Training with continuous feedback
  - Early detection of inter annotator disagreement triggers guideline enforcement / revision

- Tooling
  - Optimised concept retrieval (fuzzy, substring, synonyms)
  - Guideline enforcement by appropriate tools
  - Postcoordination support (complex syntactic expressions instead of simple concept grouping)
Prevention: improve SNOMED CT quality

- Fill gaps
  - Add missing equivalence axioms
  - Self-explaining labels, text definitions where necessary
- Preference rules to manage polysemy
- Strengthen ontological foundations
  - Upper-level ontology alignment
  - Better distinction between domain entities and information entities
  - Overhaul problematic subhierarchies, especially qualifiers
Prevention: improve content maintenance

- Data-driven terminology maintenance
  - Harvest notorious disagreements between annotations from clinical datasets
  - Detect imbalances by analysing concept frequency and co-occurrence between comparable institutions
  - Community processes: crowdsourcing of interface terms by languages, dialects, specialties, user groups
    (ASSESS-CT: interface terminologies to be maintained separately from reference terminologies)
Remediation of annotation disagreements
## Remediation of annotation disagreements

### Exploit ontological dependencies / implications

<table>
<thead>
<tr>
<th>Concept A</th>
<th>Concept B</th>
<th>Dependency</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Mast cell neoplasm (disorder)'</td>
<td>'Mast cell neoplasm (morphologic abnormality)'</td>
<td>A subclassOf AssociatedMorphology some $B$</td>
</tr>
<tr>
<td>'Isosorbide dinitrate (product)'</td>
<td>'Isosorbide dinitrate (substance)'</td>
<td>A subclassOf HasActiveIngredient some $B$</td>
</tr>
<tr>
<td>'Palpation (procedure)'</td>
<td>'Palpation - action (qualifier value)'</td>
<td>A subclassOf Method some $B$</td>
</tr>
<tr>
<td>'Blood pressure taking (procedure)'</td>
<td>'Blood pressure (observable entity)'</td>
<td>A subclassOf hasOutcome some $B$</td>
</tr>
<tr>
<td>'Increased size (finding)'</td>
<td>'Increased (qualifier value)'</td>
<td>A subclassOf isBearerOf some $B$</td>
</tr>
<tr>
<td>'Finding of heart rate (finding)'</td>
<td>'Heart rate (observable entity)'</td>
<td>A subclassOf Interprets some $B$</td>
</tr>
</tbody>
</table>
Experiment

- **Gold standard expansion:**
  - Step 1: include concepts linked by attributive relations:
    - $A \text{ subclassOf } \text{Rel some } B$
  - Step 2: include additional first-level taxonomic relations:
    - $A \text{ subclassOf } B$

<table>
<thead>
<tr>
<th>Language of text sample</th>
<th>Gold standard expansion</th>
<th>F measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>no expansion</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>expansion step 1</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>expansion step 2</td>
<td>0.29</td>
</tr>
</tbody>
</table>

- only insignificant improvement
- possibly due to missing relations in SNOMED CT (see "former smoker" and "skeletal muscle normal" examples)
- just a side issue... requires more investigation
Conclusions
Conclusions

- Poor agreement hampers SNOMED CT use:
  - Clinical decision support, cohort building, content retrieval, summarisation, analytics,... (but not specific for SNOMED CT → ACCESS CT)

- Prevention & Remediation:
  - Education, tooling, guidelines
  - Large-scale SNOMED CT content and structure improvement
  - High coverage local interface terminologies, representing real language of clinicians
Outlook

- "Learning systems" for improvement terminology content / structure / tooling.
- "Clinical big data": pooling of non-re-identifiable annotations from multiple institutions.
- Community efforts for interface terminology creation and maintenance.
- Post processing of SNOMED CT annotations: Stream of codes $\rightarrow$ text knowledge graph.

*Martínez-Costa, Kalra, Schulz. Semantic enrichment of clinical models towards semantic interoperability. JAMIA 2015 May;22(3):565-76*
Thanks for your attention

- Slides will be made accessible at purl.org/steschu
- Acknowledgements: ASSESS CT team: Jose Antonio Miñarro-Giménez, Catalina Martínez-Costa, Daniel Karlsson, Kirstine Rosenbeck Gøeg, Kornél Markó, Benny Van Bruwaene, Ronald Cornet, Marie-Christine Jaulent, Päivi Hämäläinen, Heike Dewenter, Reza Fathollah Nejad, Sylvia Thun, Veli Stroetmann, Dipak Kalra
- Contact: stefan.schulz@medunigraz.at
Ecosystem of semantic assets

- Terminologies
- Information Models
- Process Models
- Guideline Models
...describe and standardize a neutral, language-independent sense
• The meaning of domain terms
• The properties of the objects that these terms denote
• Representational units are commonly called “concepts”
• RTs enhanced by formal descriptions = "Ontologies"
Information Models

Guideline Models

Core Reference Terminology

- Systems of non-overlapping classes in single hierarchies, for data aggregation and ordering.
- aka classifications, e.g. the WHO classifications
- Typically used for health statistics and reimbursement

Aggregation Terminologies (Classifications)
• Reference and aggregation terminologies represent / organize the domain
• They are not primarily representations of language
• They use human language labels as a means to univocally describe the entities they denote, independently of the language actually used in human communication

• Systems of non-overlapping classes in single hierarchies, for data aggregation and ordering.
• aka classifications, e.g. the WHO classifications
• Typically used for health statistics and reimbursement
User Interface Terminology (language specific)

- Collections of terms used in written and oral communication within a group of users
- Terms often ambiguous.
- Entries in user interface terminologies to be further specified by language, dialect, time, sub(domain), user group.
MUG-GIT: Creation of German Interface Terminologie for SNOMED CT

Human Validation
- dependent on use cases
- e.g. input for official translation
- e.g. starting point for crowdsourcing process for interface term generation
- lexicon for NLP approaches

Human curation
- correct most frequent mistranslations
- remove wrong translations
- check POS tags
- normalise
- adjectives add synonyms

Term reassembling heuristics

Rules

Reference corpus (DE)

Clinical corpus (DE)

Raw full terms (DE)

All SCT descriptions (EN)

Non-Translatable SCT descriptions

Translatable SCT descriptions (EN)

n-grams (EN)

n-grams (DE)

Token translations

untranslated tokens

n-gram translations

Char translation rule acquisition

POS tags

New Token translations

Human curation

New Token translations

POS tags

Curated ngram translations (DE)

Term reassembling heuristics

Phrase generation rules

Chunker

Rules

Translatable SCT descriptions (EN)

Google Translate

n-grams (EN)

filter concepts with identical terms across translations
<table>
<thead>
<tr>
<th>Term</th>
<th>Frequency</th>
<th>German Translation</th>
<th>English Translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>vaginal</td>
<td>1</td>
<td>vaginales</td>
<td>Scheiden-</td>
</tr>
<tr>
<td>fluoroscopic guidance</td>
<td>2</td>
<td>Durchleuchtungskontrolle</td>
<td>Monitoring</td>
</tr>
<tr>
<td>disc</td>
<td>1</td>
<td>Scheibe</td>
<td>Encephalon</td>
</tr>
<tr>
<td>lower limb</td>
<td>2</td>
<td>unteres</td>
<td>Encephalon</td>
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<td>brain</td>
<td>1</td>
<td>Gehirn</td>
<td>Encephalon</td>
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<td>preparation</td>
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<td>Zubereitung</td>
<td>Aufbereitung</td>
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<td>Verfahren</td>
<td>Methode</td>
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<td>of bone</td>
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<td>Knochen_</td>
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<td>Überwachung</td>
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