ChaTEAU: A Universal Toolkit for Applying the CHASE

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ABSTRACT

What do applications like semantic optimization, data exchange and integration, answering queries under dependencies, query reformulation with constraints, and data cleaning have in common? All these applications can be processed by the CHASE, a family of algorithms for reasoning with constraints. While the theory of the CHASE is well understood, existing implementations are confined to specific use cases and application scenarios, making it difficult to reuse them in other settings. ChaTEAU overcomes this limitation: It takes the logical core of the CHASE, generalizes it, and provides a software library for different CHASE applications in a single toolkit.

1 INTRODUCTION

The CHASE is a widely applicable technique for reasoning with constraints. It takes a parameter * and an object \bigcirc as input, and forms a result that corresponds to the combination of both. In this way, the parameter is incorporated into the object, so that * is explicitly contained in \bigcirc , denoted CHASE $_{*}(\bigcirc) = (*)$. The versatile applicability of the CHASE is due to the fact that one can pass different types of objects and parameters as input. Instead of considering queries and instances separately (as other implementations do), ChaTEAU generalizes both to a CHASE object. Similarly, the CHASE parameter in ChaTEAU generalizes dependencies, queries, and views by treating them uniformly as logic formulas.

Applying the CHASE to instances [5] and queries [7] behaves in a similar manner, because the structure of queries and instances is also quite similar. However, existing CHASE tools such as PDQ [4], Llunatic [8], or Graal [3] are limited to specific use cases, e.g., semantic optimization, data cleaning and exchange, or query answering with existential rules. These different use cases can be reduced to the processing of instances and queries. With ChaTEAU (CHASE for Transforming, Evolving, and Adapting databases and queries, Universal Approach) we have developed and implemented a universal CHASE tool that abstracts instances and queries to a general CHASE object and parameter. The software, examples, and further information are available at our Git repository¹.

The uniform treatment of CHASE use cases and variants in ChaTEAU makes it ideal for embedding it in different applications, e.g., for data exchange, data cleaning, or query reformulations with constraints. For specific applications, additional extensions such as provenance or a second BACKCHASE-phase may be necessary. These extensions are being added gradually to ChaTEAU and can be selected individually depending on the target use case. We are currently integrating *where-*, *why-* and *how-*provenance [10] to provide provenance-supported applications as well.

Structure of the article: Section 2 describes our CHASE generalization; Section 3 discusses the ChaTEAU implementation. Finally, the ChaTEAU demonstration and GUI are presented in Section 4, using a concrete example.

2 GENERALIZATION OF THE CHASE

Recall that the CHASE modifies a given object \bigcirc , called *CHASE object*, by incorporating a parameter * (the *CHASE parameter*), which we can write as CHASE $_*(\bigcirc) = (*)$. While \bigcirc can represent both queries and instances, we understand * as set of constraints formalized as (s-t) tgds and/or egds. An *equality generating dependency (egd)* is a formula of the form $\forall \mathbf{x}(\phi(\mathbf{x}) \rightarrow (x_1 = x_2))$. A formula of the form $\forall \mathbf{x}(\phi(\mathbf{x}) \rightarrow \exists \mathbf{y} : \psi(\mathbf{x}, \mathbf{y}))$ is called (*source-to-target*) tuple generat*ing dependency ((s-t) tgd)* with ϕ (*body*) and ψ (*head*) conjunctions of atomic formulas over a source and target schema, respectively. If the source and target schemas are the same, the constraint is simply a tgd. As their names suggest, egds and tgds derive new equalities and new tuples (with \exists -quantified variables), respectively.

First approaches to extend the *Standard CHASE* [5] to arbitrary objects and parameters can be found in [2]. Note that the CHASE parameter * either represents intra-database dependencies (as tgds or egds) or inter-database dependencies (as s-t tgds). The hierarchy in Figure 1 shows how other dependencies can be represented as either (s-t) tgds or egds.

The Chase object \bigcirc is either a query Q or a database instance I. In both cases, variables and null values can be replaced by other variables and null values or constants. The variable substitution rules depend on certain conditions. Let's have a closer look at them.

CHASE Parameter. The CHASE parameter * consists of a set of dependencies Σ in the form of egds or (s-t) tgds. These are generalizations of the classical *functional dependencies (FD)* and *join dependencies (JD)*. Any condition that can be written as a set of (s-t) tgds and egds can be used as a CHASE parameter. This includes views, queries, and integrity constraints as seen in Figure 1.

CHASE Object. The database tuple STUDENT(3, 'Max', 'Math') and the query atom STUDENT(y_{id} , x_{name} , 'Math') are very similar in structure. A CHASE object is an abstraction of both. The tuple consists of constants (c_i) and null values (η_1) while the expression contains (implicitly) \forall -quantified variables (x_i), \exists -quantified variables (y_i) and constants (c_i).

A database *instance I* over schema *R* consists of finite relations $R_1^I, ..., R_k^I$, where each relation R_i^I has the same arity as the relation symbol R_i . Each tuple $(x_1, ..., x_n)$ in R_i^I consists of constants c_i or null values η_i . A *conjunctive query* is a first-order formula of the form $\exists y : \phi(x, y) \rightarrow \psi(x)$ with $\phi(x, y)$ a conjunction of logic atoms (the *body*) and $\psi(x)$ a single atom (the *head*). The terms in ϕ are

¹Git repository: https://git.informatik.uni-rostock.de/ta093/ChaTEAU-demo

 \forall -quantified or ∃-quantified variables, or constants. The head ψ must not contain ∃-variables.

A query Q can be transformed into a *frozen instance* I_Q , in which each atom of Q's body is represented as a tuple in I_Q [6]. There are different ways to deal with the variables in Q. Often \exists -variables are transformed into null values and \forall -variables are treated as *labeled null* values or special constants. For the transformation of a conjunctive query Q into a generalized instance, the atoms in the body have to be written as generalized tuples. We create tuples with \exists - and \forall -variables, e.g., as follows:

 $Q = \exists y_{id} : \text{student}(y_{id}, x_{name}, 'Math') \rightarrow (x_{name})$

 $I_Q = \{\text{STUDENT}(y_{\text{id}}, x_{\text{name}}, \text{'Math'})\}.$

These generalized tuples can be extended to a generalized instance, as described in Definition 2.1. While ChaTEAU can handle general s-t tgds, here we focus on queries, which can be seen as s-t tgds with a single atom in the head.

Definition 2.1. Let *I* be an instance and *Q* a conjunctive query. A *generalized instance* is either:

- a set of (conventional) relations R^I₁, ..., R^I_k, i.e., where tuples consist of constants and null values, or
- a set of generalized tuples, consisting of the atoms of *φ*(*x*, *y*), with constants, ∀-variables, and ∃-variables.

The CHASE for Generalized Instances. Due to the different kinds of CHASE objects O_i , the CHASE steps $I_{O_i} \rightarrow I_{O_{i+1}}$ have to be generalized too, when using (s-t) tgds and egds. In ChaTEAU, we thus extend the Standard CHASE [5] to a *CHASE for generalized instances* (see Algorithm 1).

The main task of the CHASE is to infer new facts. To this end, we need to find mappings (*homomorphisms*) between the dependencies Σ and the CHASE object *O*. Using these, the CHASE maps a set of dependencies Σ into *O*. The result is a modified CHASE object *O'*. Between *O* and *O'* we also have a homomorphism.

Definition 2.2. Let $\phi(\mathbf{x})$ be the body and $\psi(\mathbf{x}, \mathbf{y})$ the head of a dependency. Let I_{O_1} and I_{O_2} be generalized instances. We define the following possible substitution rules:

- (1) a constant can be mapped to itself: $c_i \mapsto c_i$
- (2) a null value can be mapped to a constant, itself, or another null value: η_i → c_i | η_i | η_j
- (3) an ∃-variable can be mapped to a constant, itself, a null value, or another ∃- or ∀-variable:
 - (a) $y_i \mapsto c_j \mid \eta_j \mid y_i \mid x_j$ (b) $y_i \mapsto c_j \mid y_i \mid y_j \mid x_j$
- (4) a ∀-variable can be mapped to a constant, a null value, itself, or another ∀- or ∃-variable:

(a) $x_i \mapsto c_j \mid \eta_j \mid x_i \mid y_j$ (b) $x_i \mapsto c_j \mid x_i$

Now a homomorphism $h : \phi(\mathbf{x}) \to I_{O_1}$ is a mapping that satisfies (1) and (4a); a homomorphism $h : \psi(\mathbf{x}, \mathbf{y}) \to I_{O_2}$ is a mapping that satisfies (1), (3a), and (4a); and a homomorphism $h : I_{O_1} \to I_{O_2}$ is a mapping that satisfies (1), (2), (3b), and (4b).

Tgds insert new tuples to instances or add atoms to a query body. These changes are created by applying a particular homomorphism, called *trigger*, from the tgd-body to the generalized instance. Egds equate variables by applying a homomorphism from the egd-body to the generalized instance. An *active trigger* is one that (1) creates

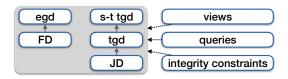


Figure 1: Constraints hierarchy and how they are formalized

new tuples or expressions by applying an (s-t) tgd, or (2) leads to a new equation of variables or null values by applying an egd.

Definition 2.3. A trigger is a homomorphism h from a dependency body to a generalized instance, i.e., $h : \phi(\mathbf{x}) \to I_O$. An active trigger is a trigger that satisfies for a

(1) tgd: no extension of *h* to an homomorphism ψ(**x**, **y**) → *I*_O,
(2) egd: *h*(*x*₁) ≠ *h*(*x*₂).

If no new tuples or equals are created during a CHASE execution, the trigger is not active. However, if an \exists -variable is contained in the tgd-head, we always have an active trigger. These variables will map to new null values or \exists -variables, depending on the type of CHASE object.

We extend the Standard CHASE to generalized instances. This new CHASE version modifies a generalized instance by a sequence of CHASE steps until all dependencies are satisfied.

Definition 2.4. Let $h : \phi(\mathbf{x}) \to I_{O_i}$ be an active trigger for a dependency σ and a generalized instance I_{O_i} . The modification of I_{O_i} to $I_{O_{i+1}}$ by applying σ under h is called *Chase step*.

Definition 2.5. Let Σ be a set of dependencies and I_{O_0} a generalized instance. The (finite) *CHASE for generalized instances* is a finite sequence of CHASE steps $I_{O_i} \rightarrow I_{O_{i+1}}$ $(0 \le i \le n)$ with

- $I_{O_n} = \bot$ (Chase fails),
- $I_{O_n} = I_{O_{n+1}}$, i.e. exists an homomorphism $h : I_{O_n} \to I_{O_{n+1}}$ with $h(z_j) = z_j$ and $z_j \in \{c_j, \eta_j, x_j, y_j\}$.

Finally, the result calculated with the CHASE on generalized instances must be interpreted. Applying an egd, the CHASE on instances fails if different constants are matched to each other, and returns \bot , whereas the CHASE on queries returns \emptyset . The CHASE result on Q corresponds to the transformation of I_{Q_n} into a new query Q'. For this, the tuples of I_{Q_n} form a conjunction of atoms in the body of Q'. The query head is formed by applying the composition of all homomorphism collected during the CHASE-execution. Thus, the CHASE implemented in ChaTEAU works on arbitrary s-t tgds.

3 CHATEAU

ChaTEAU runs on different types of CHASE parameters and objects, which are automatically recognized and processed accordingly. Different constraint and termination checks are applied. The results of these tests and of the individual CHASE steps are stored in a log.

Input and Output. Input and output of instances, queries, and constraints to ChaTEAU is done through special XML files. The input file defines the schema, consisting of the relation schemas and dependencies (the CHASE parameter), as well as an instance or a query (the CHASE object).

Algorithm 1 CHASE for generalized instances (Σ, I_{O_0})		
Req	uire: set of dependencies Σ , a database instance I_{O_0}	
Ens	ure: modified database instance I_{O_n}	
1:	while $I_{O_i} \neq \bot$ and $I_{O_{i-1}} \neq I_{O_i}$ do	
2:	for all trigger h for $\sigma \in \Sigma$ do	
3:	if <i>h</i> is an active trigger then	
4:	if σ is a tgd then	
5:	extending h and adding new tuples to instance I_{O_i}	
6:	else if σ is an egd then	
7:	if values compared are different constants then	
8:	$I_{O_{j+1}} = \bot$	
9:	else	
10:	substitute null values and variables by other null	
	values, variables, or constants	

Termination. Inserting tuples that contain null values may cause non-termination of execution. This happens whenever tgds interact and trigger each other and generate new null values each time they are used. Conditions that guarantee a fixed point of a CHASE sequence exists are called *termination conditions*, and several of these can be found in [9]. ChaTEAU implements five of them: rich acyclicity, weak acyclicity, safety, acyclicity, and acyclicity with egd rewriting.

Acyclicity is a very powerful condition based on constraint rewriting [9], which is extensible and easy to implement. Commonly found is the test for weak acyclicity, such as in Llunatic [8] or Graal [3]. It can be expanded to rich acyclicity and safety without much effort. Additionally, we decided to implement acyclicity with egd rewriting to better handle the problem of egds which are ignored in most termination criteria [9].

API. ChaTEAU is a stand-alone application for the CHASE. It is implemented as a Maven project and can easily be accessed through the GUI presented in Section 4. In addition, ChaTEAU can

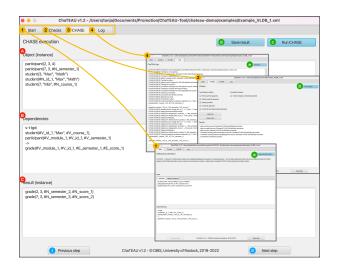


Figure 2: Overview of ChaTEAU (zoomable in pdf version)

be accessed via its API, making it easy to employ it as building block or library for developing other CHASE-based applications.

In our research project *ProSA* [2], e.g., we combine provenance management with the CHASE algorithm to compute the inverses of evaluation queries. ProSA is a tool that employs a variant of the CHASE on instances, called CHASE&BACKCHASE, so ChaTEAU is called twice: once for the CHASE and once for the BACKCHASE [1].

Further development of ChaTEAU. We extended ChaTEAU further by adding additional features. For example, **where-**, **why-**, and **how**-provenance [10] — as needed for ProSA — have already been implemented. However, provenance is not part of the CHASE itself, but is required for integration into ProSA or other applications. Therefore, this feature can only be used via the API, and not through the GUI. Other extensions such as a general attribute-constant comparisons or the integration of negated atoms and relations are still in progress. We are also continuing work on new ChaTEAU applications, as presented in [2].

4 **DEMONSTRATION**

The ChaTEAU GUI (see Figure 2) is divided into four tabs: Start (1), Tests (2), Chase (3) and Log (4). The demo starts by opening a special XML file called *ChaTEAU file* (3). It contains the CHASE parameters as a set of dependencies and the CHASE object. The ChaTEAU system automatically determines whether the object is a query or an instance and adjusts the associated tags (4) and (3) accordingly. Before executing the CHASE in the third step (3), termination and constraint checks are performed (2). A variety of tests can be selected and executed sequentially. The relevant log can be found on the last tab (4).

We will navigate in ChaTEAU using the two buttons Previous step (1) and Next step (1) at the bottom of the window. Within the upper right corner of each tab, there is an option to save or execute something (a - a).

4.1 CHASE on Instances

Even though the CHASE on instances and queries works the same in ChaTEAU, we present them as separate use cases. We start with an example for chasing instances. Both examples can be found in the corresponding demo repository.

Start. Instead of manually entering formulas, the fields for the CHASE object (Input) and parameter (Dependencies) are automatically generated from the selected XML file.

We consider an instance (object) and a query (parameter) formalized as an s-t tgd that generates a table of grades from a student and a participant table. Thus, known attributes like ID and MOD-ULE are adopted and new null values for SEMESTER and SCORE are introduced. In addition, all students not named Max are filtered out.

Instance:	{participant(2,3,4), participant(7,3,#N_semester_1),	
<pre>student(3,'Max','Math'), student(#N_id_1,'Max','Math'), student(7,'Mia',#N_course_1)}</pre>		
Dependencies:		
participant(#V_module_1,#	rticipant(#V_module_1,#V_id_1,#V_semester_1), student(#V_id_1,'Max',#V_course_1)	
	->grade(#V_module_1,#V_id_1,#E_semester_1,#E_score_1)	

Termination. ChaTEAU implements five common termination tests, from which the user can choose. When the button Run select-ed checks (b) is pressed, all checks will be run. The process can be repeated as often as desired (e.g. with different termination checks).

In our example, the CHASE terminates according to all five criteria. Also the constraint check is successful.

```
tgds are richly acyclic -> Standard CHASE will definitely terminate.
tgds are weakly acyclic -> Standard CHASE will definitely terminate.
tgds are safe -> Standard CHASE will definitely terminate.
Constraint rewriting shows that tgds are acyclic -> CHASE will definitely terminate.
Constraints are defined correctly.
```

CHASE Execution. The key part of ChaTEAU is the CHASE application in the third tab. In addition to the input (A and B), we also see the CHASE result (O) here, which can be saved (d). Despite negative termination tests, the CHASE can still be executed. In this case, an alert appears. If the CHASE is still running, it can be stopped by clicking the Start CHASE button (O) again, which is now labeled as a Stop button. The CHASE steps can be reviewed in the log (4).

Our result instance by applying CHASE matches the result of the SQL query SELECT * FROM participant NATURAL JOIN student WHERE name = 'Max' to the instance defined above:

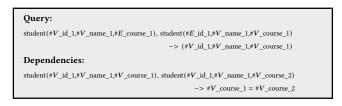
```
Result (instance):
grade(7,3,#N_semester_2,#N_score_1), grade(2,3,#N_semester_3,#N_score_2)
```

Logging. The CHASE execution is finished after three steps (1 - 3). The log offers additional information such as the results of the single CHASE steps after application of a (s-t) tgd or egd and details regarding the termination checks carried out. The log is especially suitable for debugging and is saved using **Q**.

4.2 CHASE on Queries

Thus ChaTEAU provides, depending on the CHASE object \bigcirc an instance or query extended by the specified parameter *. We continue with an example for chasing queries.

Start. We consider a query (object) and a constraint (parameter) formalized as egd. The egd replaces the \exists -quantified variable $\#E_course_1$ with the \forall -quantified variable $\#V_course_1$ by equating the attributes $\#V_course_1$ and $\#V_course_2$.



Termination and Logging. Both termination and logging behave as for instances. All six checks are satisfied.

CHASE Execution. Applying the CHASE provides the substitution of #*E*_course_1 described above. As a result, the body has changed, while the head remains the same.

Result (query):

5 CONCLUSION

The CHASE implemented in ChaTEAU can be applied to queries and instances. ChaTEAU combines these two approaches by incorporating a set of views, queries, and dependencies formalized as (s-t) tdgs and egds, called CHASE parameter, into a general CHASE object. For this, queries can be interpreted as frozen instances. This also means that a different treatment of queries and instances is no longer needed. ChaTEAU thus offers a versatile implementation of a family of reasoning algorithms, which can be easily integrated into other CHASE-based applications such as ProSA [2].

ACKNOWLEDGMENTS

We thank all the students who were involved in developing Cha-TEAU. In particular, we would like to mention Martin Jurklies, Fabian Renn, Florian Rose, Michael Albus, Eduard Buch, Lukas Görtz, Moritz Hanzig, Eric Maier, Rocco Flach and Chris Röhrs. We also thank Bertram Ludäscher for comments and suggestions.

REFERENCES

- Auge, T.: Extended Provenance Management for Data Science Applications. In: *PhD@VLDB, CEUR Workshop Proceedings*, Vol. 2652, CEUR-WS.org (2020)
- [2] Auge, T., Heuer, A.: ProSA Using the CHASE for Provenance Management. In: ADBIS, LNCS, Vol. 11695, pp. 357–372. Springer (2019)
- [3] Baget, K.-F., Leclère, M., Mugnier, M.-L., Rocher, S., Sipieter, C.: Graal: A Toolkit for Query Answering with Existential Rules. In: *RuleML, LNCS*, Vol. 9202, pp. 328–344, Springer (2015)
- [4] Benedikt, M., Leblay, J., Tsamoura, E.: PDQ: Proof-driven Query Answering over Web-based Data. In: PVLDB, 13(7), pp. 1553–1556 (2014)
- [5] Benedikt, M., Konstantinidis, G., Mecca, G., Motik, B., Papotti, P., Santoro, D., Tsamoura, E.: Benchmarking the Chase. In: PODS, pp. 37–52, ACM (2017)
- [6] Deutsch, A., Nash, A., Remmel, J. B.: The chase revisited. In: PODS, pp. 149–158, ACM (2008)
- [7] Deutsch, A., Popa, L., Tannen, V.: Physical Data Independence, Constraints, and Optimization with Universal Plans. In: VLDB, pp. 459–470, Morgan Kaufmann (1999)
- [8] Geerts, F., Mecca, G., Papotti, P., Santoro, D.: Cleaning data with Llunatic. In: VLDB J., 4(29), pp. 867–892 (2020)
- [9] Greco, S., Spezzano, F., Trubitsyna, I.: Stratification Criteria and Rewriting Techniques for Checking Chase Termination. In: Proc. VLDB Endow., 4(11), pp. 1158-1168 (2011)
- [10] Herschel, M., Diestelkämper, R., Ben Lahmar, H.: A survey on provenance What for? What form? What from?. In: VLDB J., 26(6), 881–906 (2017)