# String Abstractions

# String Verification

- Given a string manipulating program, *string analysis* determines *all possible values* that a string expression can take during any program execution

- Using string analysis we can verify properties of string manipulating programs
  - For example, we can identify all possible input values of sensitive functions in a web application and then check *whether inputs of sensitive functions can contain attack strings*

# Regular Abstraction

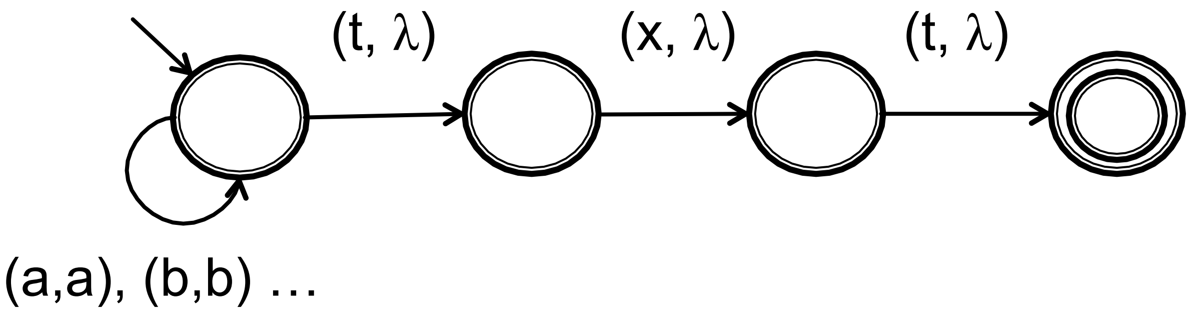
- Configurations/Transitions are represented using word equations

- Word equations are represented/approximated using (aligned) *multi-track DFAs* which are closed under intersection, union, complement and projection

- Operations required for reachability analysis (such as equivalence checking) are computed on DFAs

# Regular Abstraction

- Let X (the first track), Y (the second track), be two string variables
- λ : a padding symbol that appears only on the tail of each track (aligned)
- A multi-track automaton that encodes X = Y.txt



# Regular Abstraction

- Compute the post-conditions of statements

Given a multi-track automata M and

an assignment statement: $X := sexp$

Post(M, X := sexp) denotes the post-condition of X := sexp with respect to M

Post(M, X := sexp)

$= (\exists X, M \cap \text{CONSTRUCT}(X' = sexp, +))[X/X']$

# Regular Abstraction

- We implement a symbolic forward reachability computation using the post-condition operations

- The forward fixpoint computation is not guaranteed to converge in the presence of loops and recursion

- We use an automata based widening operation to over-approximate the fixpoint
  - Widening operation over-approximates the union operations and accelerates the convergence of the fixpoint computation

# Abstractions on String Contents

- The alphabet of an *n*-track automaton is $\Sigma^n$
  - The size of multi-track automata could be huge during computations
  - On the other hand, we may carry more information than we need to verify the property

- More Abstractions:
  - We propose *alphabet abstraction* to reduce $\Sigma$
  - We propose *relation abstraction* to reduce n

# Alphabet Abstraction

- Select a subset of alphabet characters (Σ′) to analyze distinctly and merge the remaining alphabet characters into a special symbol (◆)

- For example:

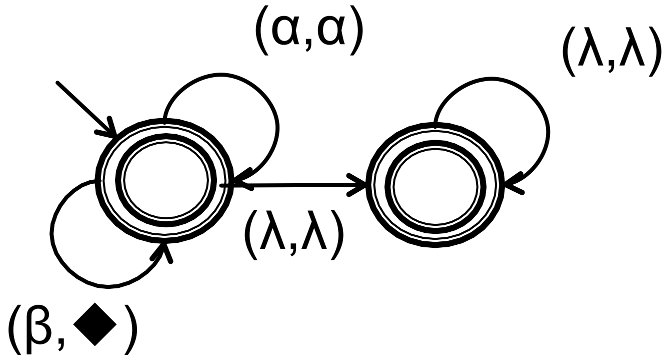
  Let $\Sigma=\{<, a, b, c\}$ and $\Sigma'=\{<\}$, $L(M) = a{<}b^+$,

  we have:

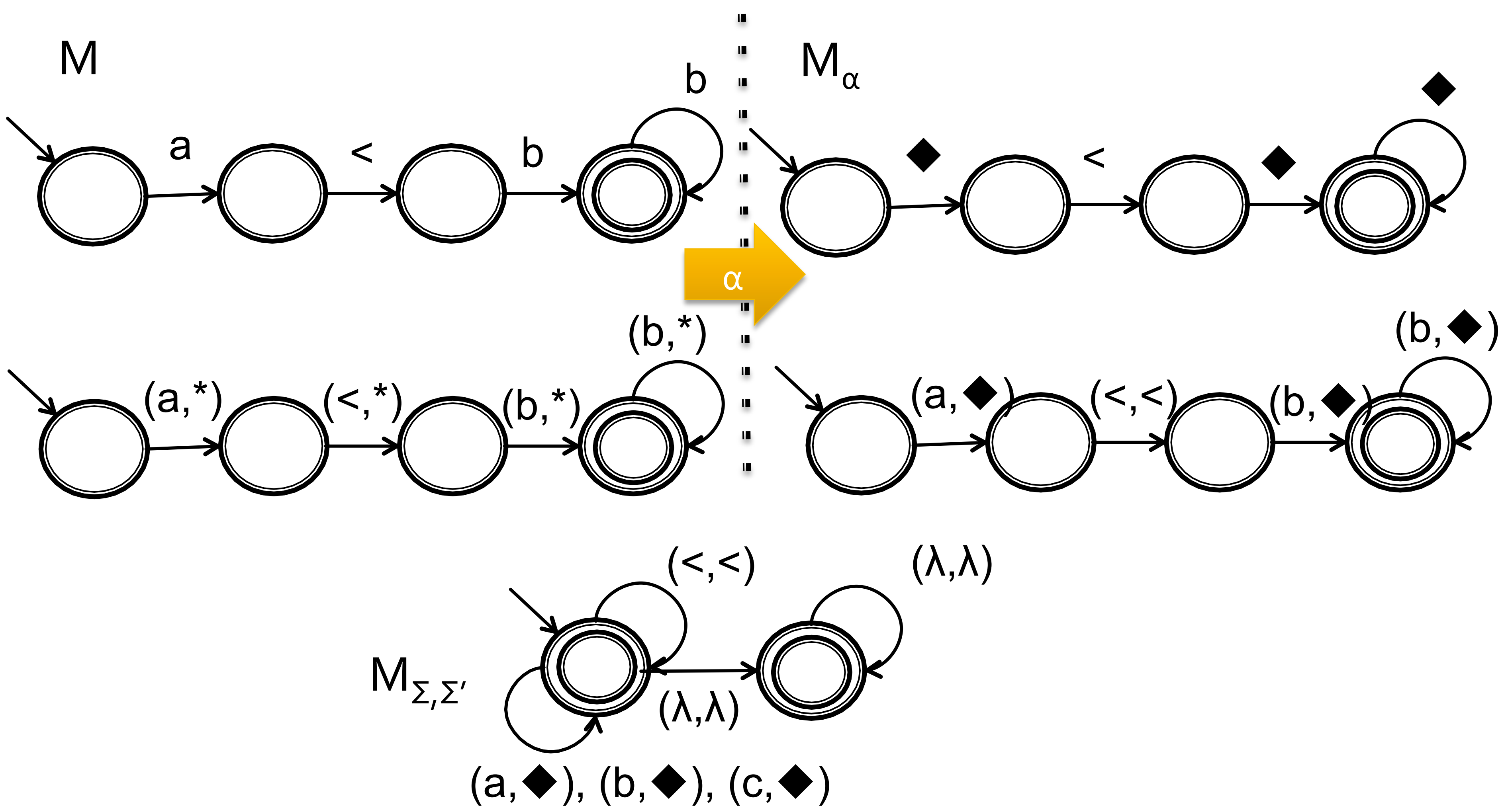
  $\alpha_{\Sigma,\Sigma'}(M) = M_\alpha$ and $\gamma_{\Sigma,\Sigma'}(M_\alpha) = M_\gamma$, where $L(M_\alpha)=\blacklozenge{<}\blacklozenge^+$, and $L(M_\gamma) = (a|b|c){<}(a|b|c)^+$

# Alphabet Transducer: $M_{\Sigma,\Sigma'}$

- We use an *alphabet transducer* $M_{\Sigma,\Sigma'}$ to construct abstract automata
  - α denotes any character in Σ′
  - β denotes any character in Σ\Σ′



# An Example of Alphabet Abstraction $\Sigma=\{<, a, b, c\}$ and $\Sigma'=\{<\}$



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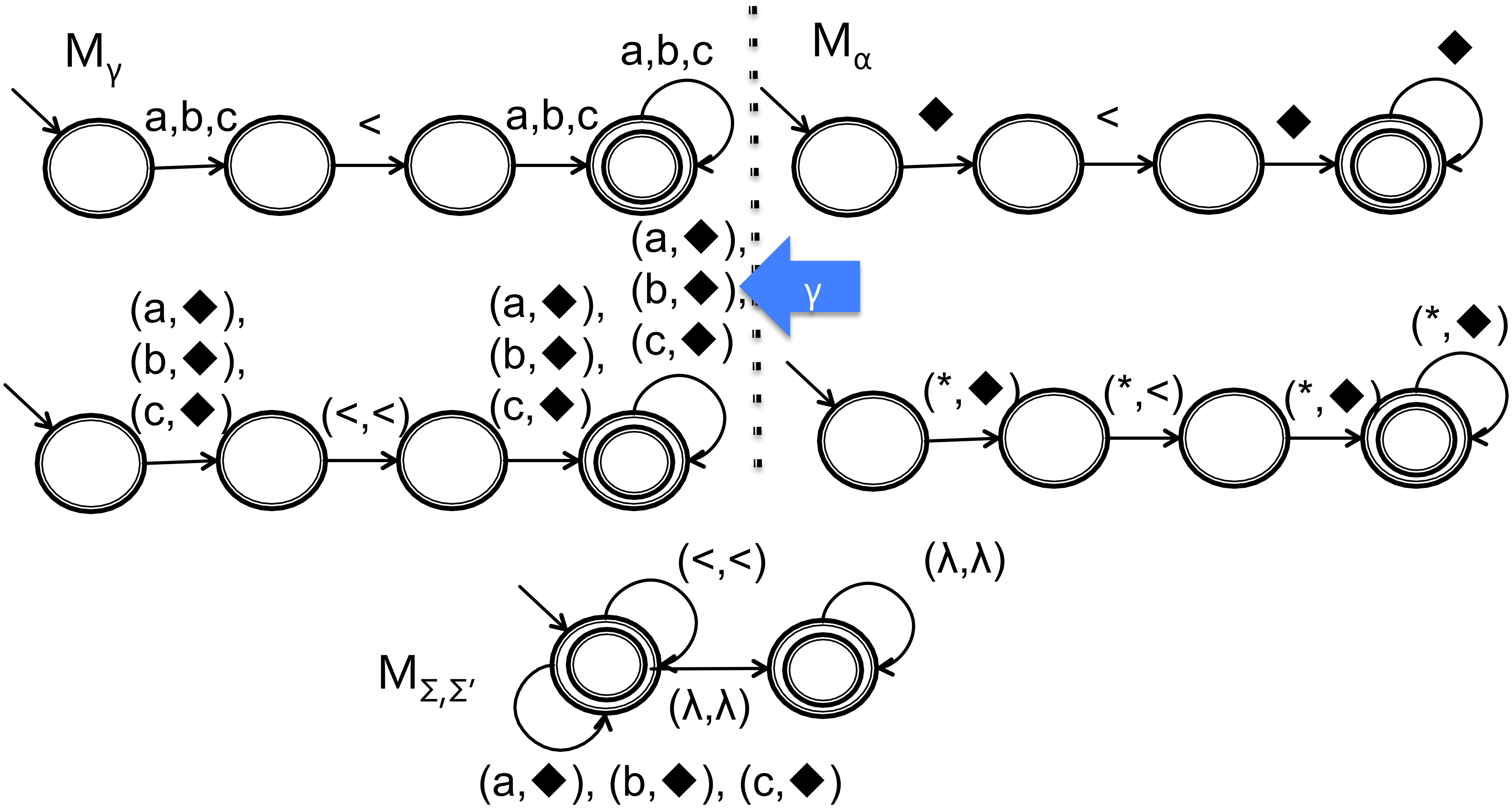


# Apply Alphabet Abstraction

```
<?php
 $www = $_GET[”www”];
 $l_otherinfo = ”URL”;
 $www = str_replace(<,””,$www);
 echo ”<td>” . $l_otherinfo . ”: ” . $www . ”</
 td>”;
?>
```

- Consider the above example, choosing Σ’={<, s} (instead of all ASCII characters) is sufficient to conclude that the echo string does not contain any substring that matches “<script”

# Length abstraction as alphabet abstraction

- Consider the following abstraction: We map all the symbols in the alphabet to a single symbol
- The automaton we generate with this abstraction will be a unary automaton (an automaton with a unary alphabet)
- The only information that this automaton will give us will be the length of the strings
- So alphabet abstraction corresponds to length abstraction

# Relation Abstraction

- Select sets of string variables to analyze relationally (using multi-track automata), and analyze the rest independently (using single-track automata)

For example, consider three string variables $n_1$, $n_2$, $n_3$.

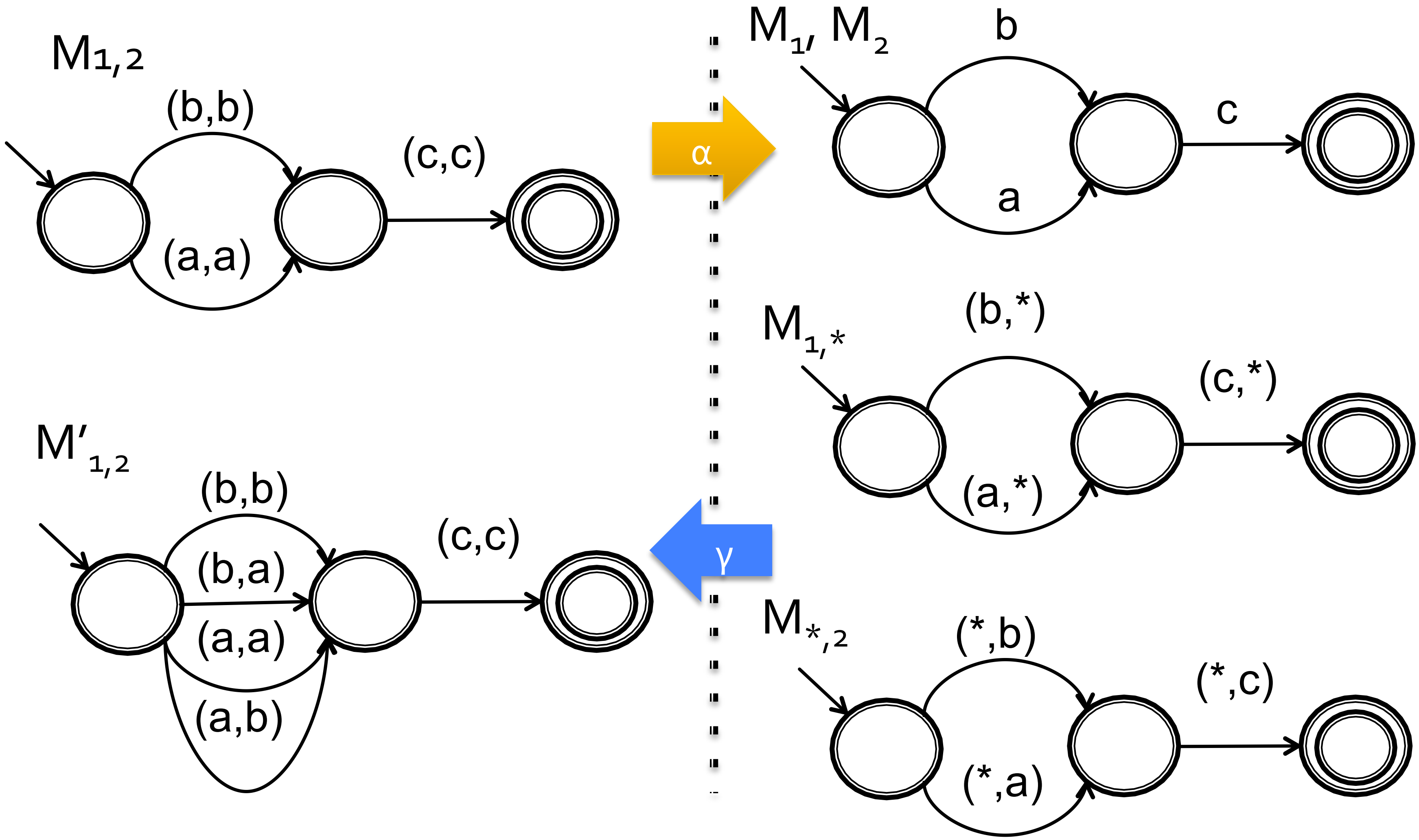
- Let $\chi=\{\{n_1,n_2\}, n_3\}$ and $\chi'=\{\{n_1\}, \{n_2\}, \{n_3\}\}$
- Let $\mathbf{M} = \{M_{1,2}, M_3\}$ that consists of a 2-track automaton for $n_1$ and $n_2$ and a single track automaton for $n_3$
- We have

$$\alpha_{\chi,\chi'}(\mathbf{M}) = \mathbf{M}_\alpha$$
$$\gamma_{\chi,\chi'}(\mathbf{M}_\alpha) = \mathbf{M}_\gamma \text{ , where}$$

# Relation Abstraction

- $\mathbf{M}_{\alpha}$ = {$M_1$, $M_2$, $M_3$} such that $M_1$ and $M_2$ are constructed by the projection of $M_{1,2}$ to the first track and the second track respectively
- $\mathbf{M}_{\gamma}$ = {$M'_{1,2}$, $M_3$} such that $M'_{1,2}$ is constructed by the intersection of $M_{1,*}$ and $M_{*,2}$ , where
  - $M_{1,*}$ is the two-track automaton extended from M1 with arbitrary values in the second track
  - $M_{*,2}$ is the two-track automaton extended from M2 with arbitrary values in the first track

# An Example of Relation Abstraction



# Apply Relation Abstraction

```
<?php
 $usr = $_GET[“usr”];
 $passwd = $_GET[“passwd”];
 $key = $usr.$passwd;
 if($key = “admin1234”)
  echo $usr;
?>
```

- Consider the above example, choosing χ′={{$usr, $key}, {$passwd}} is sufficient to identify the echo string is a prefix of “admin1234” and does not contain any substring that matches “<script”

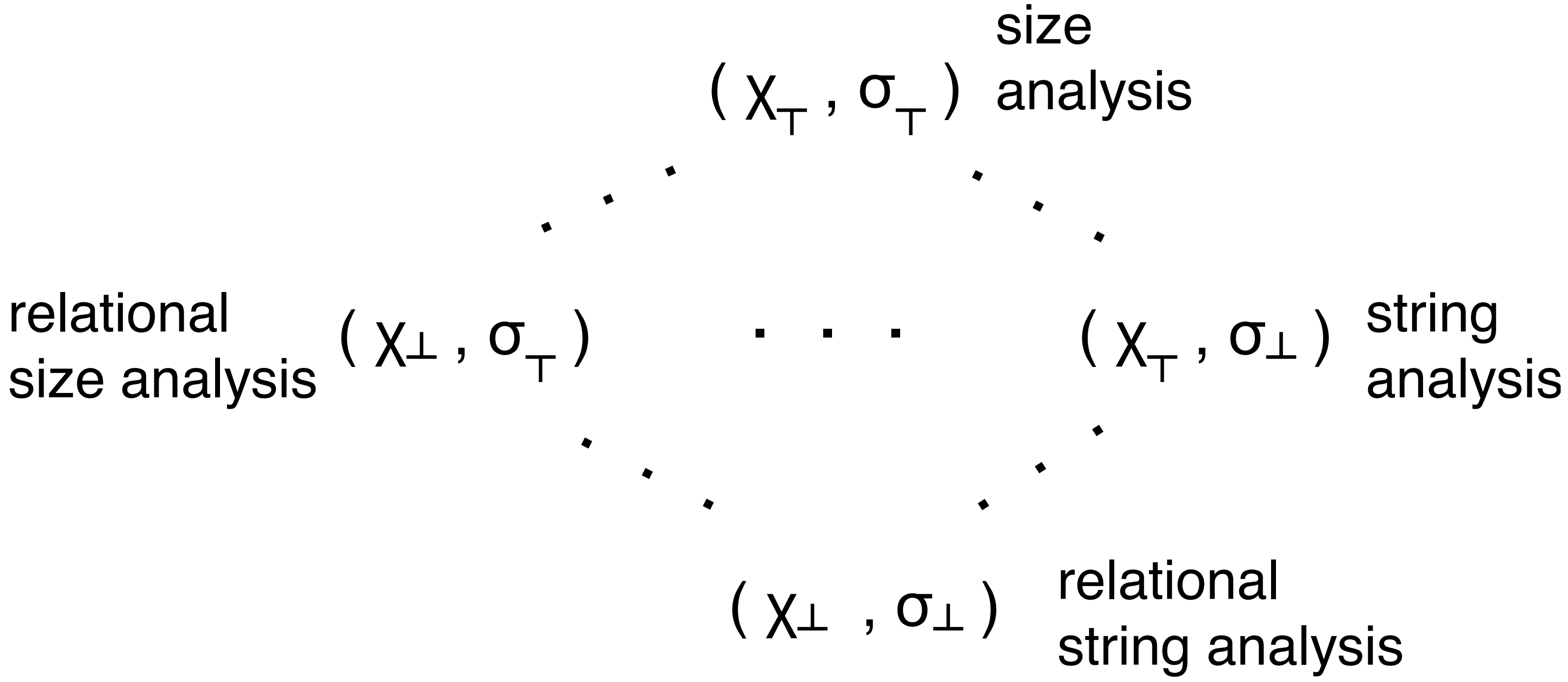
# Abstraction Lattice

- Both alphabet and relation abstractions form abstraction lattices, which allow different levels of abstractions

- Combining these abstractions leads a product lattice, where each point is an *abstraction class* that corresponds to a particular alphabet abstraction and a relation abstraction
  - The top is a non relational analysis using unary alphabet
  - The bottom is a complete relational analysis using full alphabet

# Abstraction Lattice

Some abstraction from the abstraction lattice and the corresponding analyses



$(\chi_\top , \sigma_\top)$ size analysis

relational size analysis $(\chi_\perp , \sigma_\top)$ . . . $(\chi_\top , \sigma_\perp)$ string analysis

$(\chi_\perp , \sigma_\perp)$ relational string analysis

# Abstraction Class Selection

- Select an abstraction class
  - Ideally, the choice should be as abstract as possible while remaining precise enough to prove the property in question
- Heuristics
  - Let the property guide the choice
  - Collect constants and relations from assertions and their dependency graphs
    - It forms the lower bound of the abstraction class
    - Select an initial abstraction class, e.g., characters and relations appearing in assertions
    - Refine the abstraction class toward the lower bound