TYPES FOR CALCULUS OF MOBILE CODE APPLICATIONS[1]

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SUMMARY

In this paper we present new type system for calculus of mobile ambients. Our approach is suitable for expressing dynamic properties of mobile code applications, where the main goal is to avoid ambiguities and possible maliciousness of some constructions in calculus of mobile ambients. We define behavioral scheme assigned to process types that statically specifies and checks access rights for authorization of ambients and threads to communicate and move. We proved the soundness theorem for the new type system and we demonstrated the system by showing how to model typical mobile code paradigms that are used to design mobile code applications.

Keywords: *ambient calculus, mobile code, type system*

1. INTRODUCTION

The calculus of mobile ambients [1] is based on concurrency paradigm represented by the π-calculus [2]. It introduces the notion of an ambient as a bounded place where concurrent computation takes place, which can contain nested subambients in a hierarchical structure, and which can move in and out of other ambients, i.e., up and down the hierarchy what rearranges the structure of ambients. The communication can only occur locally within each ambient through a common anonymous channel. Communication between different ambients has to be performed by movement and by dissolution of ambient boundaries.

The ambition of mobile ambients is in general to express mobile computation and mobile computing. Mobile ambients can express in natural way dynamic properties (communication and mobility) of mobile code systems, but there is still question of deeper control and verification of mobility properties (like access rights or mobility control). Usual approaches apply type systems which add more properties to the pure calculus. Our paper presents the type system for ambient calculus that abstracts various properties of mobility and communication as a behavioral scheme of a process.

Mobile ambients model several computational entities: mobile agents, mobile processes, messages, packets or frames, physical or virtual locations, administrative and security domains in a distributed system and also mobile devices. This variety makes that in principle there are no differences among various kinds of software components when expressing by mobile ambients. In mobile ambients there are implicitly two main forms of entities, which we will respectively call threads and ambients. Threads are unnamed sequences of primitive actions to be executed sequentially, generally in concurrency with other threads. They can perform communication and drive their containers through the spatial hierarchy, but cannot individually go from one ambient to another. Ambients are named containers of concurrent threads. They can enter and exit other ambients, driven by their internal processes, but cannot directly perform communication. It is very important to ensure indivisibility and autonomous behavior of ambients (this is also important e.g. for objects).

Communication between ambients is represented by the movement of other ambient of usually shorter life, which have their boundaries dissolved by an *open* action to expose their internal threads performing local communication operations. Such capability of opening an ambient is potentially dangerous [3, 4, 5]. It could be used inadvertently to open and thus destroy the individuality of an object or mobile agent. Remote communication is usually emulated as a movement of such ambients (communication packages) in the hierarchy structure.

We explore a different approach, where we intend to keep the purely local character of communication so that no hidden costs are present in the communication primitives, but without *open* operation. This solves the problem of dissolving boundaries of ambients, but disables interactions of threads from separate ambients. We have to introduce new operation *move* for moving threads between ambients. The idea comes from mobile code programming paradigms [6] where moving threads can express strong mobility mechanism, by which the procedure can (through *move* operation) suspend its execution on one machine and resume it exactly from the same point on another (remote) machine. This solves the problem of threads mobility and by moving threads between ambients we can emulate communication between the ambients.

Such adaptations of mobile ambients operations we can express computational entities of mobile programs in more natural way. Another purpose for

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this approach is to prefer simplicity and understandability of designed type system for mobile ambients later on.

2. THE AMBIENT CALCULUS

We define abstract syntax and operational semantics of our calculus. It is based on abstract syntax and operational semantics of ambient calculus including our new constructions.

2.1. Abstract Syntax

The abstract syntax of the terms of our calculus in Tab. 1 is the same as that of mobile ambients except for the absence of *open* and the presence of the new operation *move* for moving threads between ambients. We allow synchronous output and the asynchronous version is its particular case.

$M ::=$	**mobility operations**
$\mid\ n$	name
$\mid\ in\ M$	move ambient into M
$\mid\ out\ M$	move ambient out of M
$\mid\ move\ M$	move thread into M
$\mid\ M.M'$	path
$P ::=$	**processes**
$\mid\ \mathbf{0}$	inactive process
$\mid\ P \mid P'$	parallel composition
$\mid\ !P$	replication
$\mid\ M[P]$	ambient
$\mid\ (\nu n : \mathbf{P}[\mathrm{B}])P$	name restriction
$\mid\ M.P$	action of the operation
$\mid\ \langle M \rangle.P$	synchronous output
$\mid\ (n : \mu).P$	synchronous input

Tab. 1 Abstract syntax

We introduce types already in the term syntax, in the synchronous input and in the name restriction. The defined terms are not exactly the terms of our calculus, since the type constructions are not yet taken into account, this is done by the typing rules in the next section.

2.2. Operational Semantics

The operational semantics is given by a reduction relation along with a structural congruence the same way as those for mobile ambients.

Each name of the process term can figure either as free (Tab. 2) or bound (Tab. 3).

$$fn(n) = \{n\}$$
$$fn(in\ M) = fn(M)$$
$$fn(out\ M) = fn(M)$$
$$fn(move\ M) = fn(M)$$
$$fn(M.M') = fn(M) \cup fn(M')$$
$$fn(\mathbf{0}) = \varnothing$$
$$fn(P \mid P') = fn(P) \cup fn(P')$$
$$fn(!P) = fn(P)$$
$$fn(M[P]) = fn(M) \cup fn(P)$$
$$fn((\nu n : \mathbf{P}[\mathrm{B}])P) = fn(P) - \{n\}$$
$$fn(M.P) = fn(M) \cup fn(P)$$
$$fn(\langle M \rangle.P) = fn(M) \cup fn(P)$$
$$fn((n : \mu).P) = fn(P) - \{n\}$$

Tab. 2 Free names

$$bn(n) = \varnothing$$
$$bn(in\ M) = bn(M)$$
$$bn(out\ M) = bn(M)$$
$$bn(move\ M) = bn(M)$$
$$bn(M.M') = bn(M) \cup bn(M')$$
$$bn(\mathbf{0}) = \varnothing$$
$$bn(P \mid P') = bn(P) \cup bn(P')$$
$$bn(!P) = bn(P)$$
$$bn(M[P]) = bn(M) \cup bn(P)$$
$$bn((\nu n : \mathbf{P}[\mathrm{B}])P) = bn(P) \cup \{n\}$$
$$bn(M.P) = bn(M) \cup bn(P)$$
$$bn(\langle M \rangle.P) = bn(M) \cup bn(P)$$
$$bn((n : \mu).P) = bn(P) \cup \{n\}$$

Tab. 3 Bound names

We write $P\{n \leftarrow M\}$ for a substitution of the capability M for each free occurrences of the name n in the term P. The similarly for $M\{n \leftarrow M\}$.

Structural congruence is shown in Tab. 4 and it is standard for mobile ambients. The (SAmbNull) rule is added to get a form of garbage collection, because of absence of the *open* operation.

equivalence:	
$P \equiv P$	(SRefl)
$P \equiv Q \Rightarrow Q \equiv P$	(SSymm)
$P \equiv Q, Q \equiv R \Rightarrow P \equiv R$	(STrans)
congruence:	
$P \equiv Q \Rightarrow P \mid R \equiv Q \mid R$	(SPar)
$P \equiv Q \Rightarrow !P \equiv !Q$	(SRepl)
$P \equiv Q \Rightarrow M[P] \equiv M[Q]$	(SAmb)

$P \equiv Q \Rightarrow (\nu n : \mathbf{P}[\mathrm{B}])P \equiv$ $(\nu n : \mathbf{P}[\mathrm{B}])Q$	(SRes)
$P \equiv Q \Rightarrow M.P \equiv M.Q$	(SAct)
$P \equiv Q \Rightarrow \langle M \rangle.P \equiv \langle M \rangle.Q$	(SCommOut)
$P \equiv Q \Rightarrow (n : \mu).P \equiv (n : \mu).Q$	(SCommIn)
sequential composition (associativity):	
$(M.M').P \equiv M.M'.P$	(SPath)
parallel composition (associativity, commutativity and inactivity):	
$P \mid Q \equiv Q \mid P$	(SParComm)
$(P \mid Q) \mid R \equiv P \mid (Q \mid R)$	(SParAssoc)
$P \mid \mathbf{0} \equiv P$	(SParNull)
replication:	
$!P \equiv P \mid !P$	(SReplPar)
$!\mathbf{0} \equiv \mathbf{0}$	(SReplNull)
restriction and scope extrusion:	
$n \neq m \Rightarrow (\nu n : \mathbf{P}[\mathrm{B}])(\nu m : \mathbf{P}[\mathrm{B}'])P \equiv$ $(\nu m : \mathbf{P}[\mathrm{B}'])(\nu n : \mathbf{P}[\mathrm{B}])P$	(SResRes)
$n \notin fn(Q) \Rightarrow (\nu n : \mathbf{P}[\mathrm{B}])P \mid Q \equiv$ $(\nu n : \mathbf{P}[\mathrm{B}])(P \mid Q)$	(SResPar)
$n \neq m \Rightarrow (\nu n : \mathbf{P}[\mathrm{B}])m[P] \equiv$ $m[(\nu n : \mathbf{P}[\mathrm{B}])P]$	(SResAmb)
$(\nu n : \mathbf{P}[\mathrm{B}])\mathbf{0} \equiv \mathbf{0}$	(SResNull)
garbage collection:	
$(\nu n : \mathbf{P}[\mathrm{B}])n[\mathbf{0}] \equiv \mathbf{0}$	(SAmbNull)

Tab. 4 Structural congruence

In addition, we identify processes up to renaming of bound names (α-conversion) as shown in Tab. 5. By this we mean that these processes are understood to be identical (e.g. by choosing an appropriate representation), as opposed to structurally equivalent.

$(\nu n : \mathbf{P}[\mathrm{B}])P =$ $(\nu m : \mathbf{P}[\mathrm{B}])P\{n \leftarrow m\}$ $m \notin fn(P)$	(SAlphaRes)
$(n : \mu)P = (m : \mu)P\{n \leftarrow m\}$ $m \notin fn(P)$	(SAlphaCommIn)

Tab. 5 α-conversion

The reduction rules in Tab. 6 are those for mobile ambients, with the obvious difference consisting in the synchronous output and the missing *open* operation, and with the new rule for the *move* operation similar to the "migrate" instructions for strong code mobility in software agents.

basic reductions:	
$n[in\ m.P \mid Q] \mid m[R] \rightarrow m[n[P \mid Q] \mid R]$	(RIn)
$m[n[out\ m.P \mid Q] \mid R] \rightarrow n[P \mid Q] \mid m[R]$	(ROut)
$n[move\ m.P \mid Q] \mid m[R] \rightarrow n[Q] \mid m[P \mid R]$	(RMove)
$(n : \mu).P \mid \langle M \rangle.Q \rightarrow P\{n \leftarrow M\} \mid Q$	(RComm)
structural reductions:	
$P \rightarrow Q \Rightarrow P \mid R \rightarrow Q \mid R$	(RPar)
$P \rightarrow Q \Rightarrow n[P] \rightarrow n[Q]$	(RAmb)
$P \rightarrow Q \Rightarrow (\nu n : \mathbf{P}[\mathrm{B}])P \rightarrow (\nu n : \mathbf{P}[\mathrm{B}])Q$	(RRes)
$P' \equiv P, P \rightarrow Q, Q \equiv Q' \Rightarrow P' \rightarrow Q'$	(RStruct)

Tab. 6 Reduction rules

3. TYPE SYSTEM

From the huge amount of complex behavioral properties of mobile processes we abstract (extract) the type system that is simple enough to be easily used for expressing communication and mobility properties of mobile ambients. The main goal of our abstraction is the control of communication and mobility. We defined some kind of access rights for movement of threads and ambients. Usual approach presents type systems with dependent types. We defined process types and operation types that are related to a behavioral scheme of the process. The behavioral scheme is a construction which controls the communication and mobility properties of the process.

3.1. Types and Behavioral Scheme

We define communication types where both peers, receiver and sender, must be of the same message type. This allows to keep the sense of the communication. It also secures the communication while only exchange of the correct messages is allowed.

The restriction of the mobility operations is defined by types applying a behavioral scheme. The scheme allows setting up the access rights for traveling of threads and ambients in the ambient hierarchy space of the system.

Types are defined in Tab. 7 where we present communication types and message types.

$\kappa ::=$	**communication type**
$\mid\ \perp$	no communication
$\mid\ \mu$	communication of messages of type μ
$\mu ::=$	**message type**
$\mid\ \mathbf{P}[\mathrm{B}]$	process with behavioral scheme B
$\mid\ \mathbf{O}[\mathrm{B\ a\ \ B'}]$	operation which changes behavioral scheme B to B′

Tab. 7 Types

The behavioral scheme is the structure B≡ $(\kappa, Reside, Pass, Move)$ which contains four components:

- κ is the communication type of the ambient's threads
- *Reside* is the set of behavioral schemes of other ambients where the ambient can stay
- *Pass* is the set of behavioral schemes of other ambients that ambient can go through, it must be $Pass \subseteq Reside$
- *Move* is the set of behavioral schemes of other ambients where ambient can move its containing thread

3.2. Typing Rules

Type environment is defined as a set $\Gamma = \{n_1 : \mu_1, \mathrm{K}\ , n_l : \mu_l\}$ where each $n_i : \mu_i$ assigns a unique type μ_i to a name n_i.

The domain of the type environment is defined by:

1. $Dom(\varnothing) = \varnothing$
2. $Dom(\Gamma, n : \mu) = Dom(\Gamma) \cup \{n\}$

We define two type formulas for our ambient calculus:

1. $\Gamma \quad M : \mu$
2. $\Gamma \quad P : \mathbf{P}[\mathrm{B}]$

Typing rules are shown in Tab. 8 and they are used to derive type formulas of ambient processes. We say the process is well-typed when we are able to derive a type formula for it using our typing rules. Well-typed processes respect the communication and mobility restrictions defined in all behavioral schemes of the system. It means such a process has the correct behavior. The type assignment system is clearly syntax-directed and keeps the system simple enough.

$\dfrac{n : \mu \in \Gamma}{\Gamma \quad n : \mu}$	(TName)
$\dfrac{\Gamma \quad M : \mathbf{P}[\mathrm{B}] \quad \mathrm{B} \in Pass(\mathrm{B}')}{\Gamma \quad in\, M : \mathbf{O}[\mathrm{B}' \text{ a } \mathrm{B}']}$	(TIn)
$\dfrac{\begin{array}{c}\Gamma \quad M : \mathbf{P}[\mathrm{B}] \quad \mathrm{B} \in Pass(\mathrm{B}') \\ Reside(\mathrm{B}) \subseteq Reside(\mathrm{B}')\end{array}}{\Gamma \quad out\, M : \mathbf{O}[\mathrm{B}' \text{ a } \mathrm{B}']}$	(TOut)
$\dfrac{\Gamma \quad M : \mathbf{P}[\mathrm{B}] \quad \mathrm{B} \in Move(\mathrm{B}')}{\Gamma \quad move\, M : \mathbf{O}[\mathrm{B} \text{ a } \mathrm{B}']}$	(TMove)
$\dfrac{\begin{array}{c}\Gamma \quad M : \mathbf{O}[\mathrm{B}'' \text{ a } \mathrm{B}'] \\ \Gamma \quad M' : \mathbf{O}[\mathrm{B} \text{ a } \mathrm{B}'']\end{array}}{\Gamma \quad M.M' : \mathbf{O}[\mathrm{B} \text{ a } \mathrm{B}']}$	(TPath)
$\dfrac{}{\Gamma \quad \mathbf{0} : \mathbf{P}[\mathrm{B}]}$	(TNull)
$\dfrac{\Gamma \quad P : \mathbf{P}[\mathrm{B}] \quad \Gamma \quad P' : \mathbf{P}[\mathrm{B}]}{\Gamma \quad P \mid P' : \mathbf{P}[\mathrm{B}]}$	(TPar)
$\dfrac{\Gamma \quad P : \mathbf{P}[\mathrm{B}]}{\Gamma \quad !P : \mathbf{P}[\mathrm{B}]}$	(TRepl)
$\dfrac{\begin{array}{c}\Gamma \quad P : \mathbf{P}[\mathrm{B}] \quad \Gamma \quad M : \mathbf{P}[\mathrm{B}] \\ \mathrm{B}' \in Reside(\mathrm{B})\end{array}}{\Gamma \quad M[P] : \mathbf{P}[\mathrm{B}']}$	(TAmb)
$\dfrac{\Gamma, n : \mathbf{P}[\mathrm{B}'] \quad P : \mathbf{P}[\mathrm{B}]}{\Gamma \quad (\nu n : \mathbf{P}[\mathrm{B}'])P : \mathbf{P}[\mathrm{B}]}$	(TRes)
$\dfrac{\Gamma \quad M : \mathbf{O}[\mathrm{B} \text{ a } \mathrm{B}'] \quad \Gamma \quad P : \mathbf{P}[\mathrm{B}]}{\Gamma \quad M.P : \mathbf{P}[\mathrm{B}']}$	(TAct)
$\dfrac{\Gamma \quad P : \mathbf{P}[\mathrm{B}] \quad \Gamma \quad M : \mu \quad \kappa(\mathrm{B}) = \mu}{\Gamma \quad \langle M \rangle.P : \mathbf{P}[\mathrm{B}]}$	(TCommOut)
$\dfrac{\Gamma, n : \mu \quad P : \mathbf{P}[\mathrm{B}] \quad \kappa(\mathrm{B}) = \mu}{\Gamma \quad (n : \mu).P : \mathbf{P}[\mathrm{B}]}$	(TCommIn)

Tab. 8 Typing rules

3.3. Soundness of the System

The usual property of subject reduction holds, which guarantees the soundness of the system by ensuring that typing is preserved by computation.

Soundness theorem: Let $\Gamma \quad P : \mathbf{P}[\mathrm{B}]$ for some Bf. Then:

1. $P \equiv Q$ implies $\Gamma \quad Q : \mathbf{P}[\mathrm{B}]$
2. $P \to Q$ implies $\Gamma \quad Q : \mathbf{P}[\mathrm{B}]$

Proof: The proof is standard, by induction on the derivations of $P \equiv Q$ and $P \to Q$. Let's consider only rule (RMove):

We assume $P = n[move\, m.P' \mid P''] \mid m[P''']$, $Q = n[P''] \mid m[P' \mid P''']$, and $\Gamma \quad n[move\, m.P' \mid P''] \mid m[P'''] : \mathbf{P}[\mathrm{B}]$. This is given by (TPar), so that $\Gamma \quad n[move\, m.P' \mid P''] : \mathbf{P}[\mathrm{B}]$ and $\Gamma \quad m[P'''] : \mathbf{P}[\mathrm{B}]$. These are given by (TAmb), so that $\Gamma \quad n : \mathbf{P}[\mathrm{B}_n]$, $\Gamma \quad move\, m.P' \mid P'' : \mathbf{P}[\mathrm{B}_n]$ and $\mathrm{B} \in Reside(\mathrm{B}_n)$ for some B_n, and $\Gamma \quad m : \mathbf{P}[\mathrm{B}_m]$, $\Gamma \quad P''' : \mathbf{P}[\mathrm{B}_m]$ and $\mathrm{B} \in Reside(\mathrm{B}_m)$ for some B_m. This is given by (TPar), so that $\Gamma \quad move\, m.P' : \mathbf{P}[\mathrm{B}_n]$, $\Gamma \quad P'' : \mathbf{P}[\mathrm{B}_n]$ and this is given by (TAct), so that $\Gamma \quad move\, m : \mathbf{O}[\mathrm{B}' \text{ a } \mathrm{B}_n]$ and $\Gamma \quad P' : \mathbf{P}[\mathrm{B}']$ for some B'. This is given by (TMove), so that $\Gamma \quad m : \mathbf{P}[\mathrm{B}_m]$, $\Gamma \quad move\, m : \mathbf{O}[\mathrm{B}_m \text{ a } \mathrm{B}_n]$ and $\mathrm{B}_m \in Move(\mathrm{B}_n)$, then $\mathrm{B}' = \mathrm{B}_m$ and $\Gamma \quad P' : \mathbf{P}[\mathrm{B}_m]$. Then according (TAmb) $\Gamma \quad n[P''] : \mathbf{P}[\mathrm{B}]$ where $\mathrm{B} \in Reside(\mathrm{B}_n)$ and $\Gamma \quad m[P' \mid P'''] : \mathbf{P}[\mathrm{B}]$ where $\mathrm{B} \in Reside(\mathrm{B}_m)$ and we conclude $\Gamma \quad n[P''] \mid m[P' \mid P'''] : \mathbf{P}[\mathrm{B}]$ from (TPar).

4. MODELING MOBILE CODE PARADIGMS

Now we can look to how our typed calculus can express mobile code paradigms. Let's assume three mobile code paradigms [7]:

- remote evaluation,
- code on demand, and
- mobile agent.

4.1. Remote Evaluation

Remote evaluation is performed when a client sends a piece of code to the server and server evaluates the code and client can get the results back from the server. Also very general client-server paradigm can be expressed similar way as remote evaluation.

We assume application of the server named *Server*, which executes transferred code *P* from the client application named *Client*. The result of the execution is sent back to the client as a message *M*.

$$Server = s[S]$$

$$Client = c[move\ s.P.move\ c.\langle M\rangle \mid (x:\mu).C]$$

$$System = Server \mid Client$$

In order to make the *System* well-typed we define following behavioral schemes of the processes in the system:

$$\mathrm{B} = (\perp, \varnothing, \varnothing, \varnothing)$$

$$\mathrm{B}_S = (\perp, \{\mathrm{B}\}, \varnothing, \varnothing)$$

$$\mathrm{B}_c = (\mu, \{\mathrm{B}\}, \varnothing, \{\mathrm{B}_s\})$$

As we can see schemes express that both *Server* and *Client* can be executed in the *System* and *Client* can move threads (code for remote evaluation) to the *Server*.

4.2. Code on Demand

Code on demand describes the situation where a client wants to perform a code that is presented by the server. Client asks for a code and server sends it to the client where it can be evaluated.

Similarly as for remote evaluation we assume application of the server named *Server*, which provides a code *P* to the client application named *Client*. *Client* application asks for the code and the result of execution is processed as message *M*.

$$Server = s[(p:\mathbf{O}[\mathrm{B}_c\ \ \mathrm{a}\ \ \mathrm{B}_s]).p.P.\langle M\rangle \mid S]$$

$$Client = c[move\ s.\langle move\ c\rangle \mid (x:\mu).C]$$

$$System = Server \mid Client$$

In order to make the *System* well-typed we define following behavioral schemes of the processes in the system:

$$\mathrm{B} = (\perp, \varnothing, \varnothing, \varnothing)$$

$$\mathrm{B}_S = (\mathbf{O}[\mathrm{B}_c\ \ \mathrm{a}\ \ \mathrm{B}_s], \{\mathrm{B}\}, \varnothing, \{\mathrm{B}_c\})$$

$$\mathrm{B}_c = (\mu, \{\mathrm{B}\}, \varnothing, \{\mathrm{B}_s\})$$

As we can see schemes express that both *Server* and *Client* can be executed in the *System*. *Server* can receive path (sequence of movement operations) for moving the code to the *Client*. *Client* can send the request for the code to the *Server*.

4.3. Mobile Agent

Mobile agent is a paradigm where an autonomous code (agent) is sent from the client to the server. By autonomous we mean that the client and server do not need to synchronize the agent invocation and the agent is running independently and concurrently within the server's place.

We assume application of the server named *Server*, where the agent application named *Agent* will be moved from its home application named *Home*. The process *P* of the agent is executed at the *Server* and after the execution, *Agent* is moved back *Home*. The movement of the *Agent* is defined by the path (sequence of in/out operations) which expresses travel plan of the agent.

$$Server = s[S]$$

$$Home = h[Agent \mid H]$$

$$Agent = a[out\ h.in\ s.P.out.s.in\ h]$$

$$System = Server \mid Home$$

In order to make the *System* well-typed we define following behavioral schemes of the processes in the system:

$$\mathrm{B} = (\perp, \varnothing, \varnothing, \varnothing)$$

$$\mathrm{B}_s = (\perp, \{\mathrm{B}\}, \varnothing, \varnothing)$$

$$\mathrm{B}_h = (\perp, \{\mathrm{B}\}, \varnothing, \varnothing)$$

$$\mathrm{B}_a = (\perp, \{\mathrm{B}, \mathrm{B}_s, \mathrm{B}_h\}, \{\mathrm{B}_s, \mathrm{B}_h\}, \varnothing)$$

As we can see schemes express that *Agent* can be executed either at the *Server* or *Home* places and also can move through those places.

5. CONCLUSIONS

We defined formal tool for expressing dynamics of mobile code applications, which is based on theory of mobile ambients. Presented changes to the ambient calculus are suitable for expressing different kinds of mobility and they avoid ambiguities and possible maliciousness of some constructions. The type system statically defines and checks access rights for authorization of ambients and threads to move by application of the process behavioral scheme. The usage of type system is limited by its very simplicity and it does not prevent more restrictive properties from being checked at runtime. We proved the soundness theorem for the type system and we demonstrated the system by showing how to model some common applications. We provided a simple language for distributed system of mobile agents. As an expressiveness test, we showed that well-known π-calculus of concurrency and mobility can be encoded in our calculus in a natural way [8].

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BIOGRAPHY

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