Supporting nested resources in MrsP

Jorge Garrido
Universidad Politécnica de Madrid (UPM), Spain

Shuai Zhao
Alan Burns
Andy Wellings
University of York, UK

Introduction – MrsP task model

- Sporadic task model

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:
  - Resources have a Local Ceiling Priority

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:
  - Resources have a Local Ceiling Priority
  - A job is (locally) blocked as most once during its execution

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:
  - Resources have a Local Ceiling Priority
  - A job is (locally) blocked as most once during its execution
    - Before executing

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:
  - Resources have a Local Ceiling Priority
  - A job is (locally) blocked as most once during its execution
    - Before executing
    - Then all resources are (locally) available

Introduction – MrsP task model

- Sporadic task model
- Preemptive fixed-priority scheduling
- Follows PCP:
  - Resources have a Local Ceiling Priority
  - A job is (locally) blocked as most once during its execution
    - Before executing
    - Then all resources are (locally) available
    - Deadlocks are prevented

MrsP - Timing Analysis

$$R_i = C_i + \max(\hat{e}, \hat{b}) + \sum_{\tau_j \in \mathbf{hpl}(i)} \left\lceil \frac{R_i}{T_j} \right\rceil C_j$$

MrsP - Timing Analysis

$$R_i = C_i + \max(\hat{e}, \hat{b}) + \sum_{\tau_j \in \mathbf{hpl}(i)} \left\lceil \frac{R_i}{T_j} \right\rceil C_j$$

$$C_i = WCET_i + \sum_{r^j \in \mathbf{F}(\tau_i)} n_i e^j$$

MrsP - Timing Analysis

$$R_i = C_i + \max(\hat{e}, \hat{b}) + \sum_{\tau_j \in \mathbf{hpl}(i)} \left\lceil \frac{R_i}{T_j} \right\rceil C_j$$

$$C_i = WCET_i + \sum_{r^j \in \mathbf{F}(\tau_i)} n_i e^j$$

$$e^j = |map(G(r^j))| c^j$$

MrsP - Timing Analysis

$$e^j = |map(G(r^j))|c^j$$

MrsP - Timing Analysis

$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}} c^j$$

MrsP - Timing Analysis

$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}} c^j$$

- One access request per processor

MrsP - Timing Analysis

$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}}\underbrace{c^j}_{\text{accessing time}}$$

- One access request per processor

MrsP - Timing Analysis

$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}}\underbrace{c^j}_{\text{accessing time}}$$

- One access request per processor
- Access time equal to execution time

MrsP - Timing Analysis

$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}}\underbrace{c^j}_{\text{accessing time}}$$

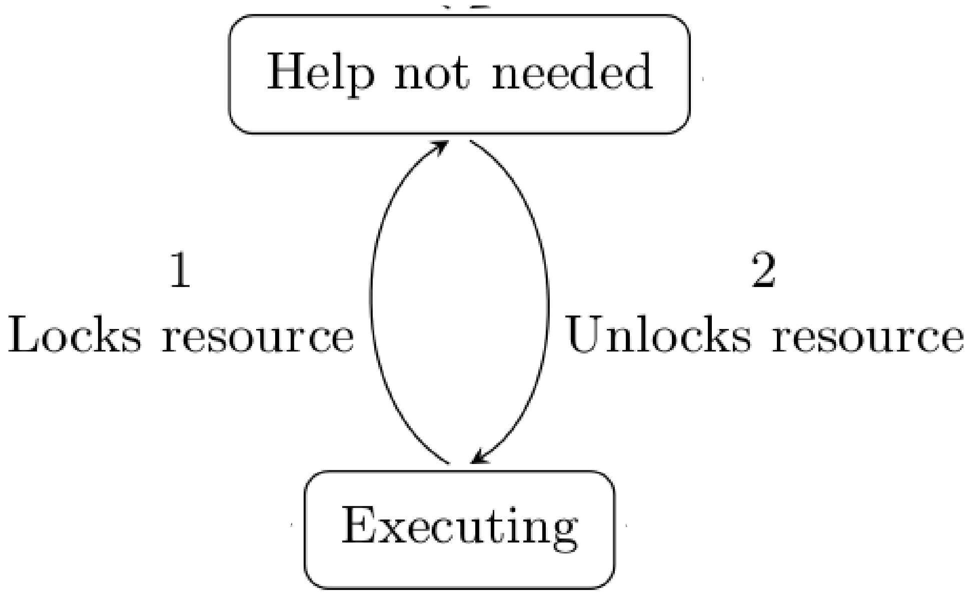
- One access request per processor
- Access time equal to execution time
  - Resource access preemptable

MrsP - Timing Analysis

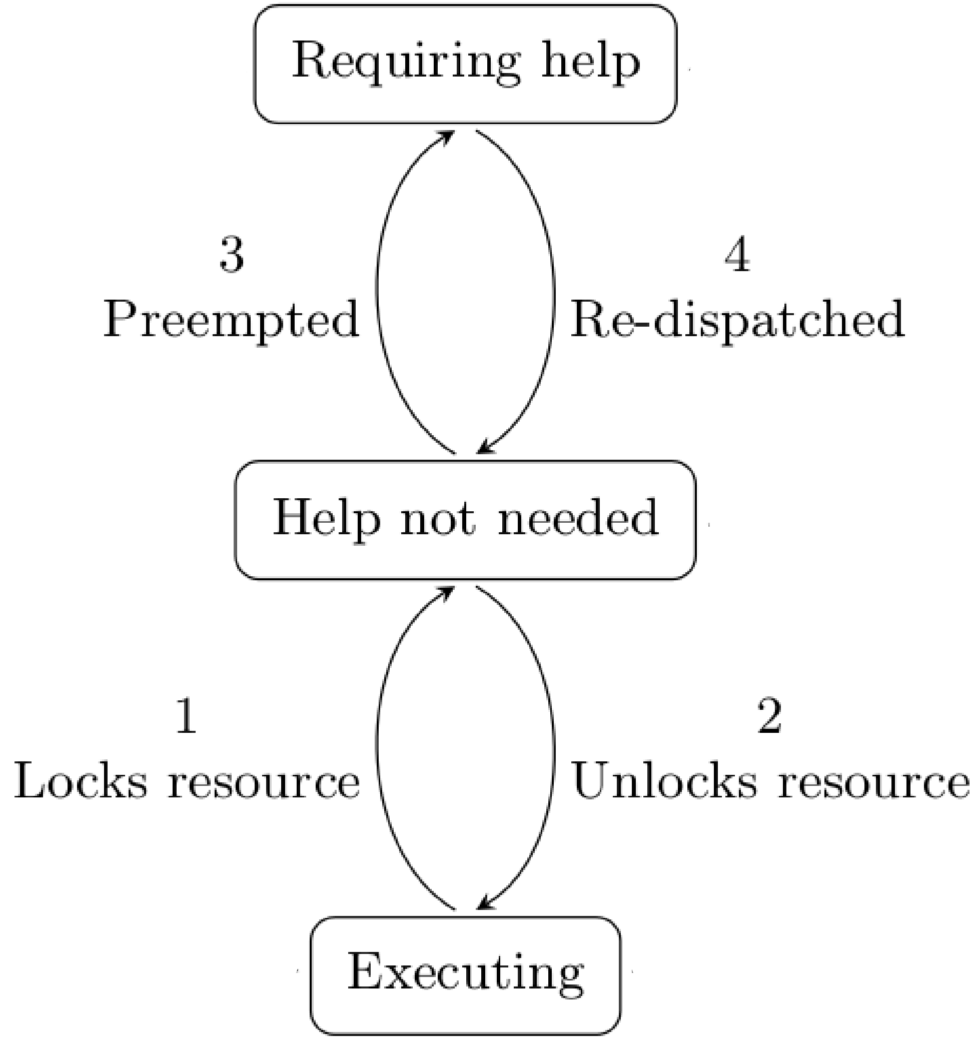
$$e^j = \underbrace{|map(G(r^j))|}_{\text{queue}}\underbrace{c^j}_{\text{accessing time}}$$

- One access request per processor
- Access time equal to execution time
  - Resource access preemptable
  - Helping mechanism

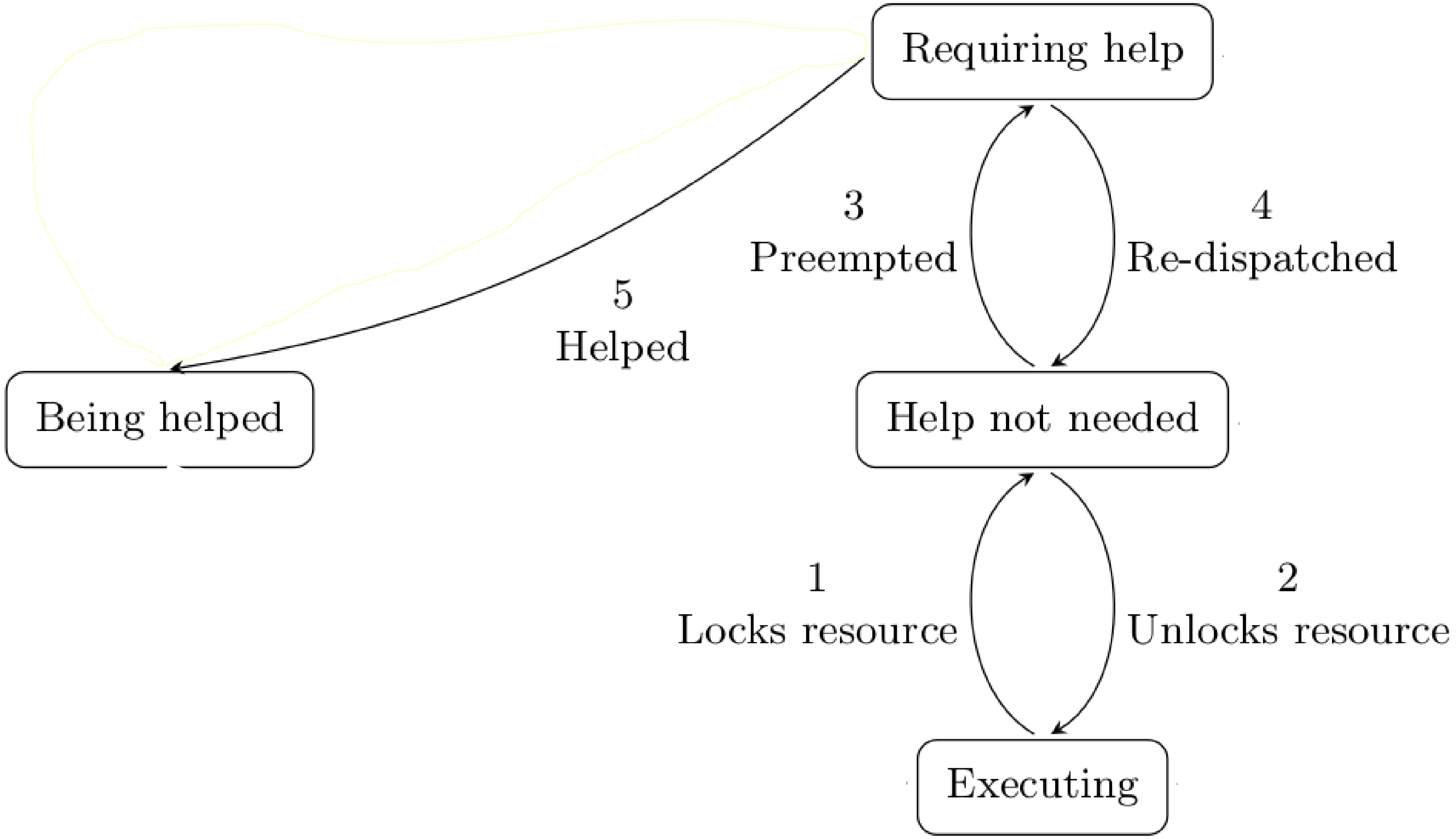
MrsP - Helping Mechanism



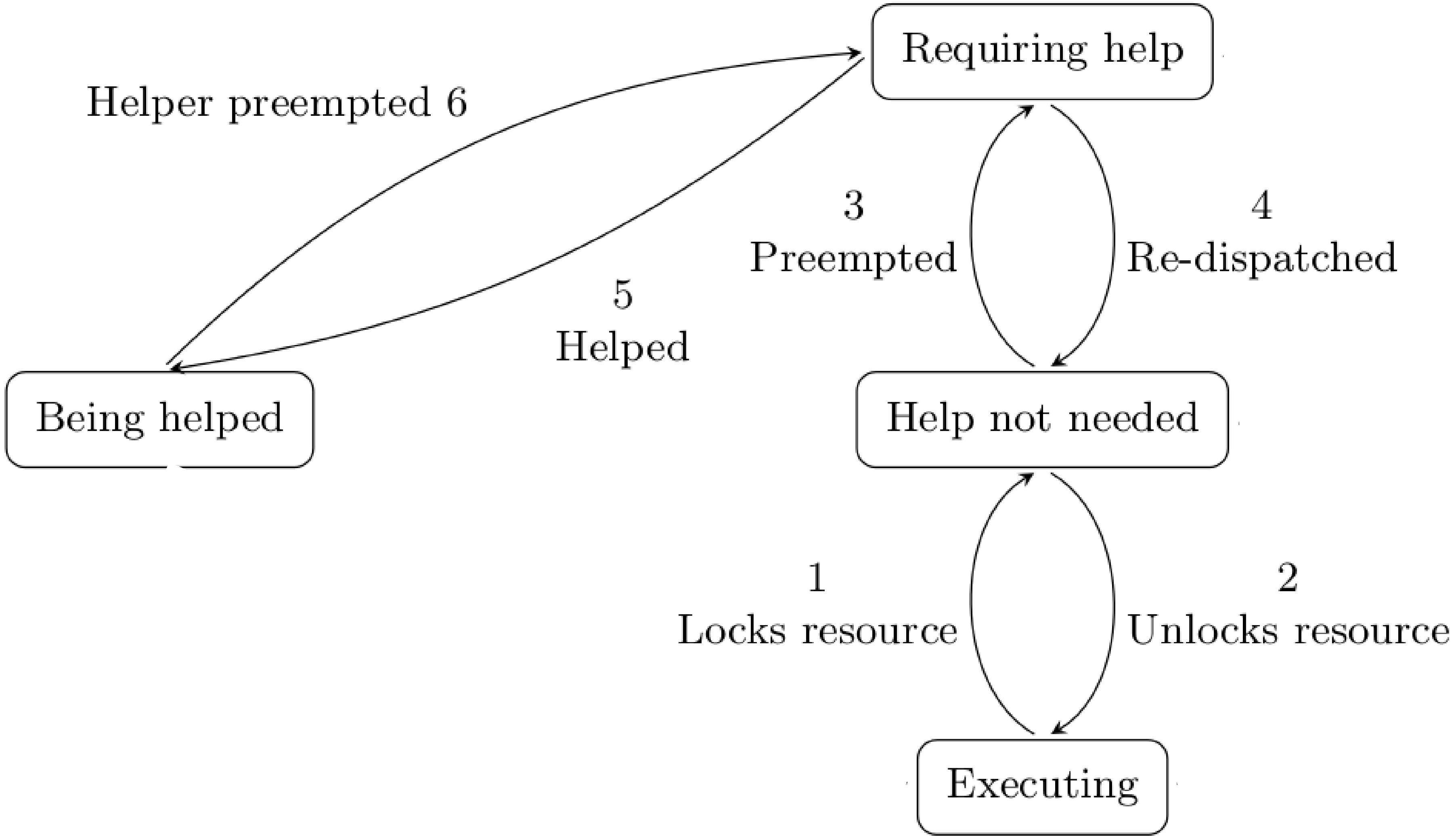
MrsP - Helping Mechanism



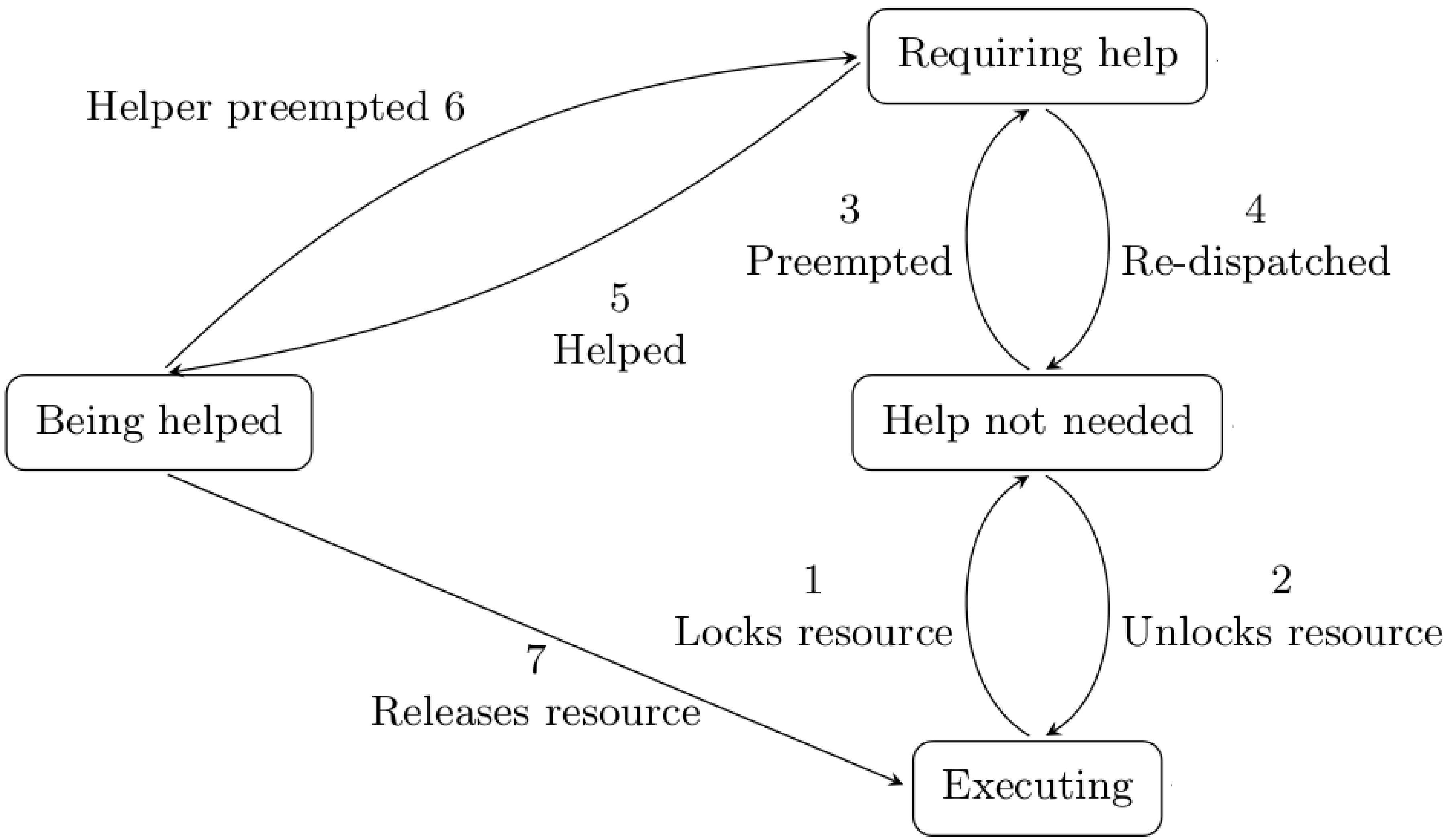
MrsP - Helping Mechanism



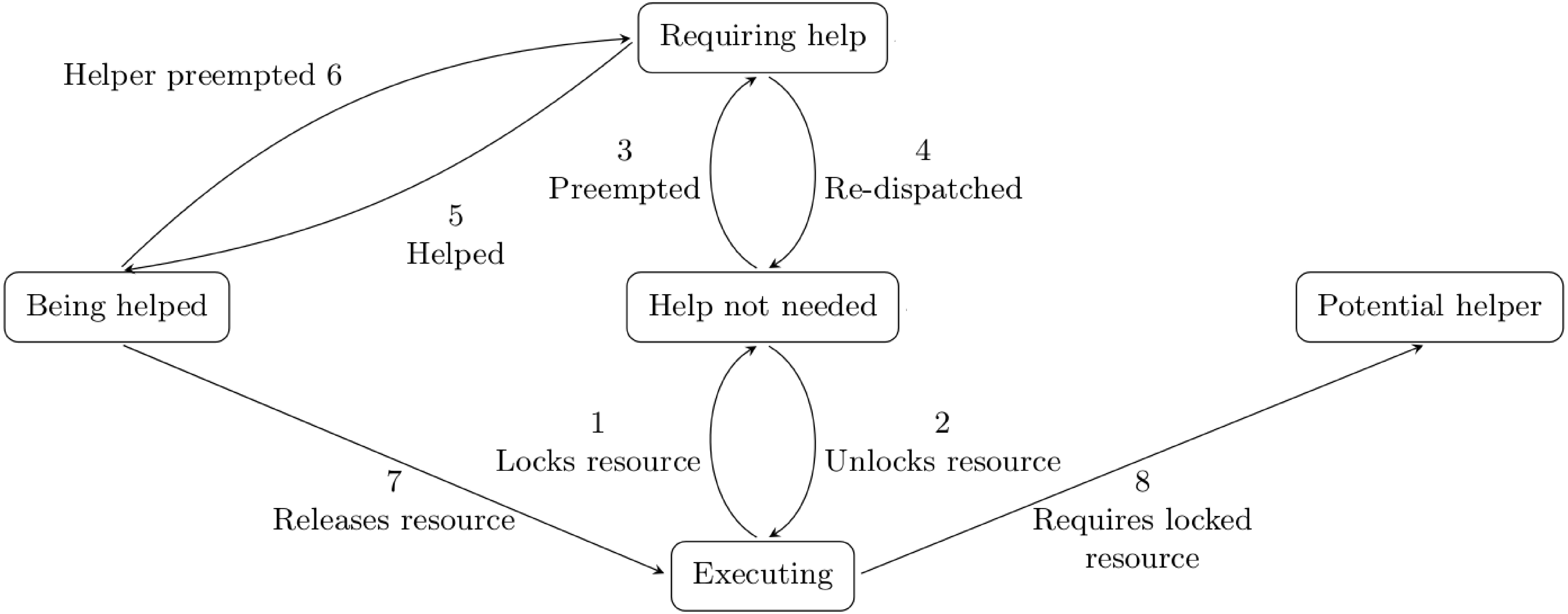
MrsP - Helping Mechanism



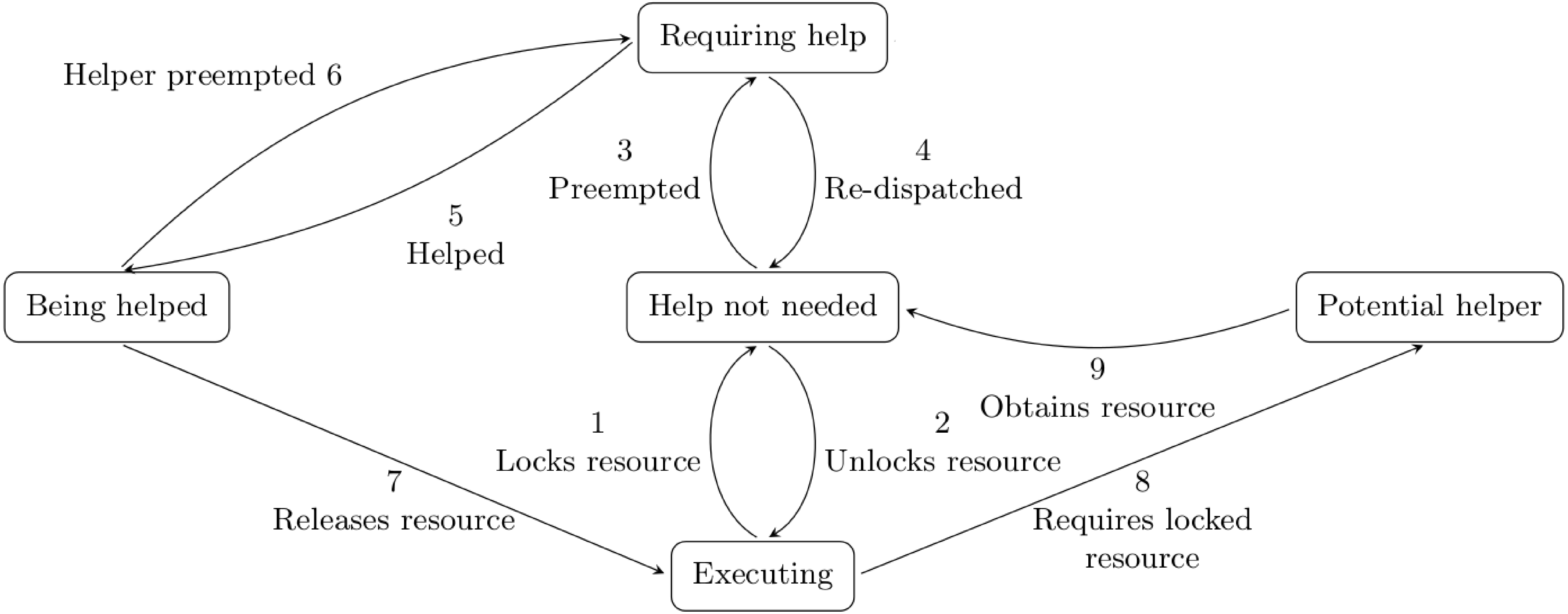
MrsP - Helping Mechanism



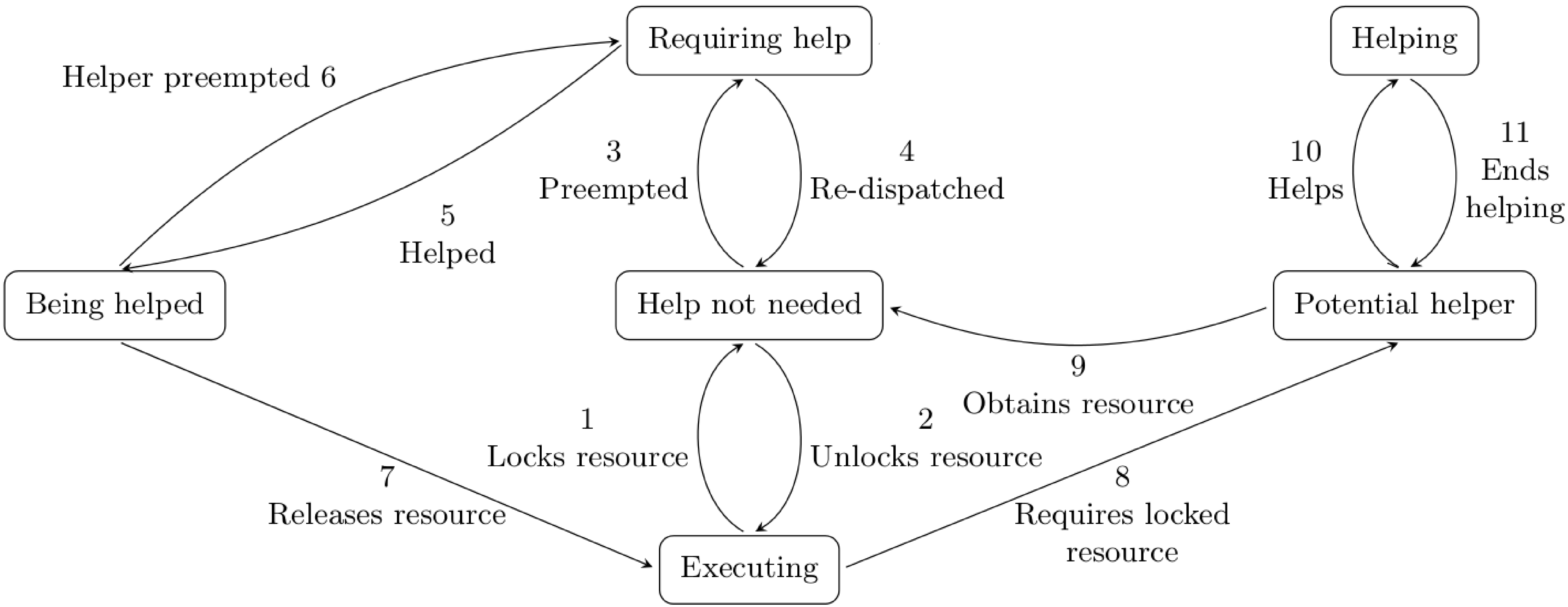
MrsP - Helping Mechanism



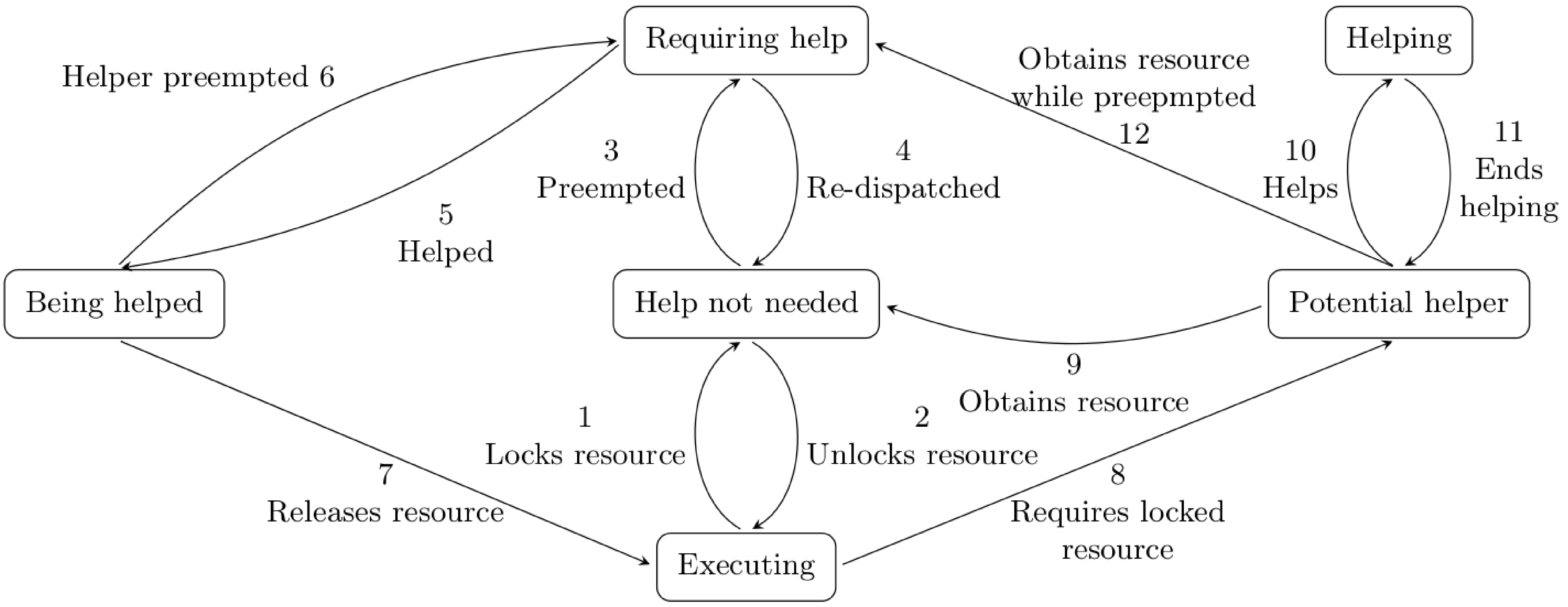
MrsP - Helping Mechanism



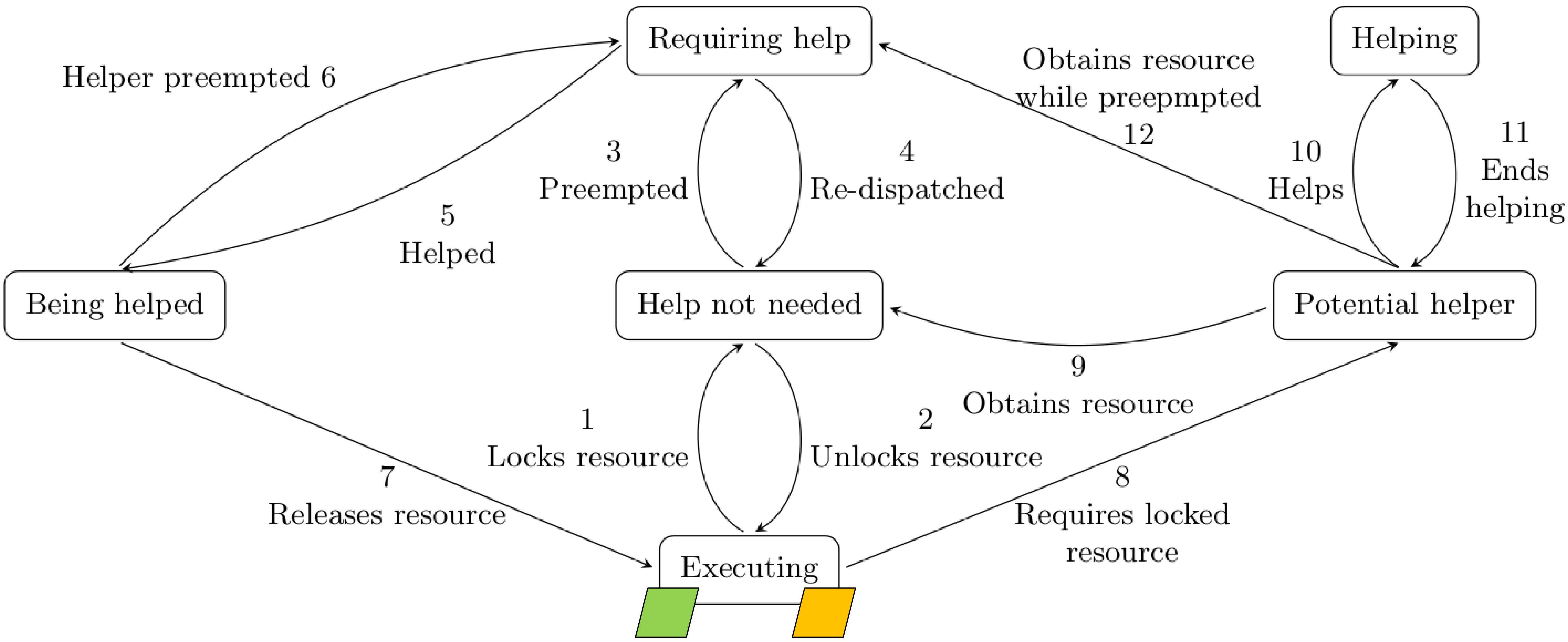
MrsP - Helping Mechanism



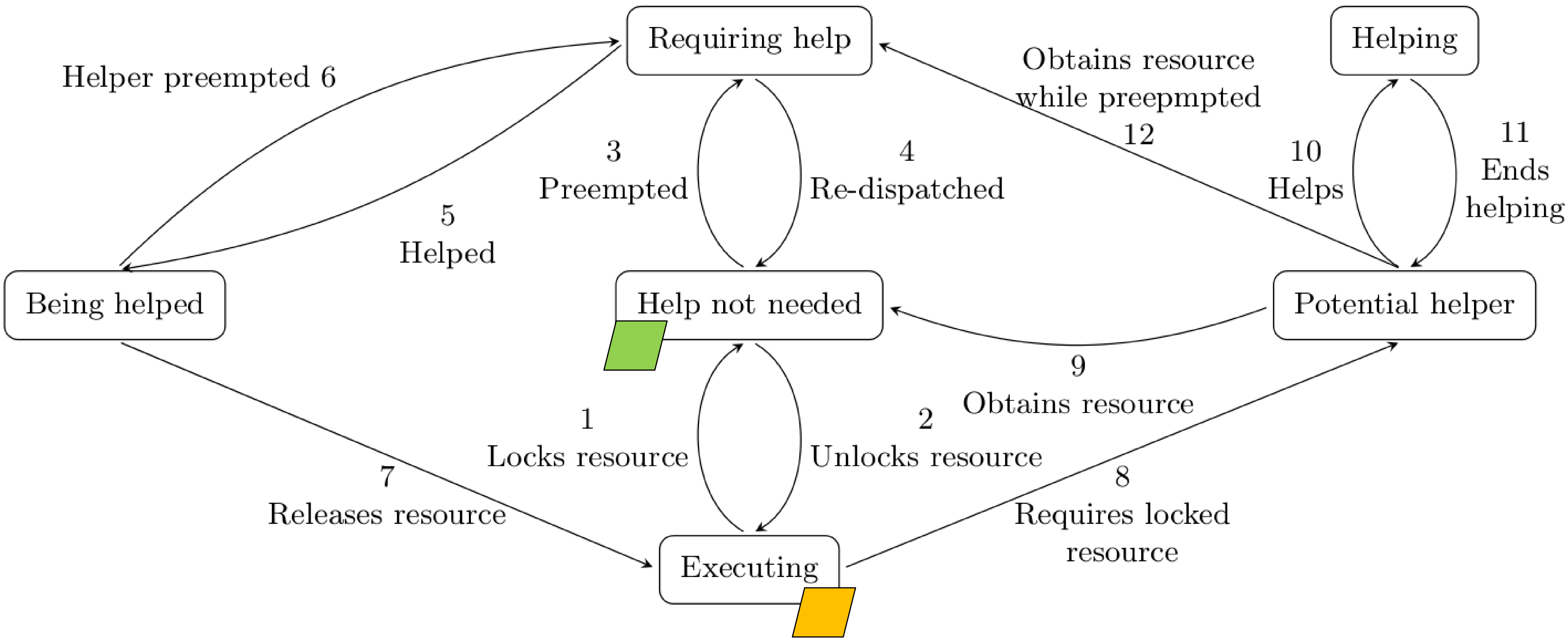
MrsP - Helping Mechanism



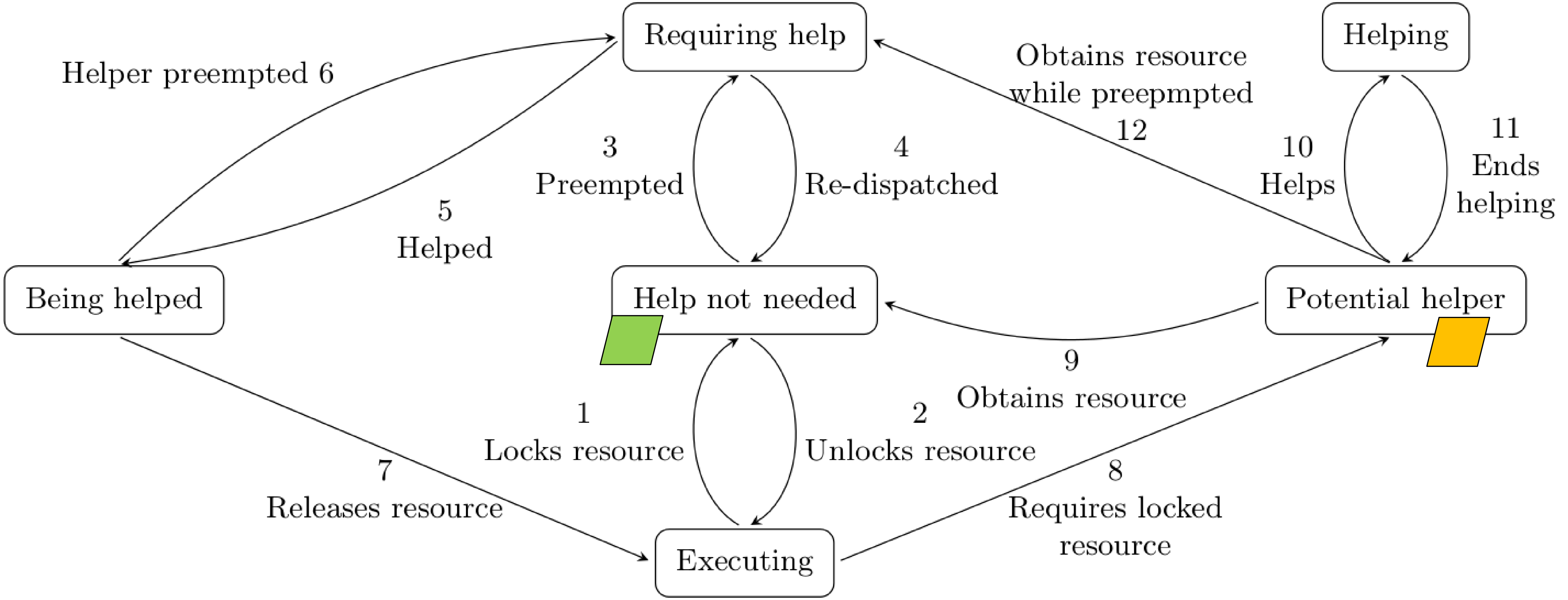
MrsP - Helping Mechanism



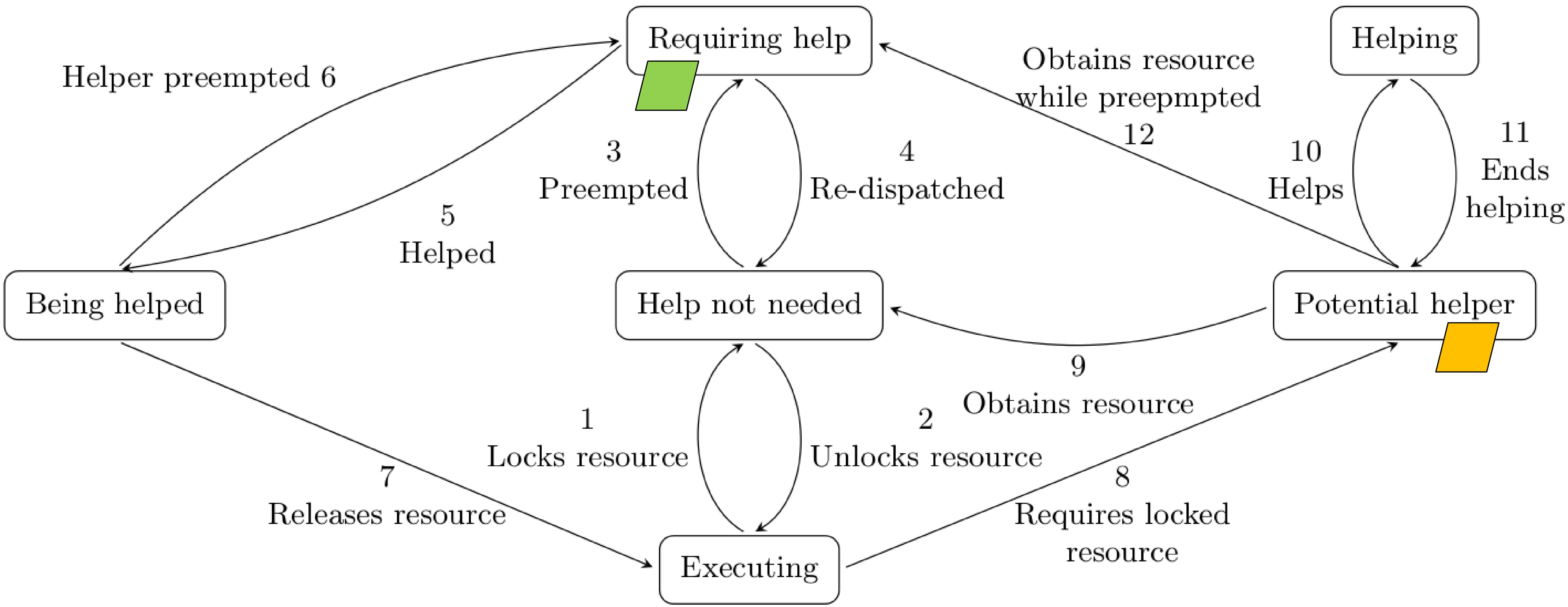
MrsP - Helping Mechanism



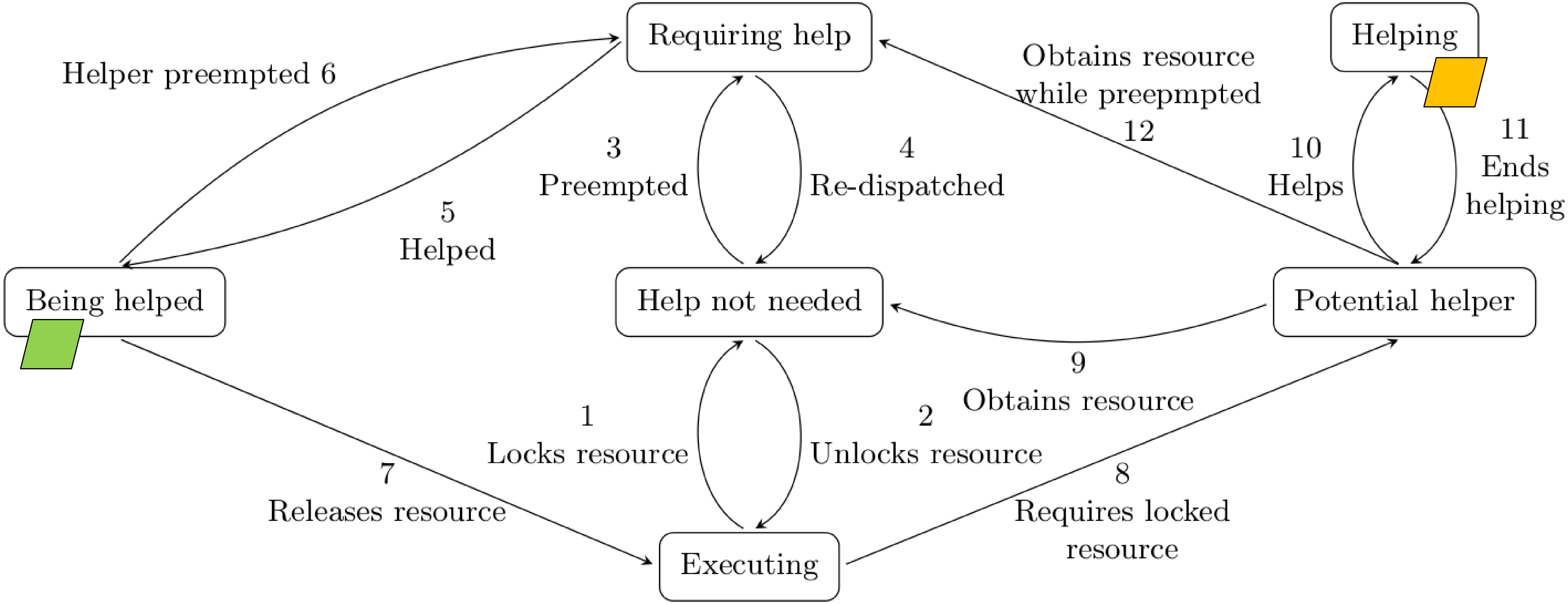
MrsP - Helping Mechanism



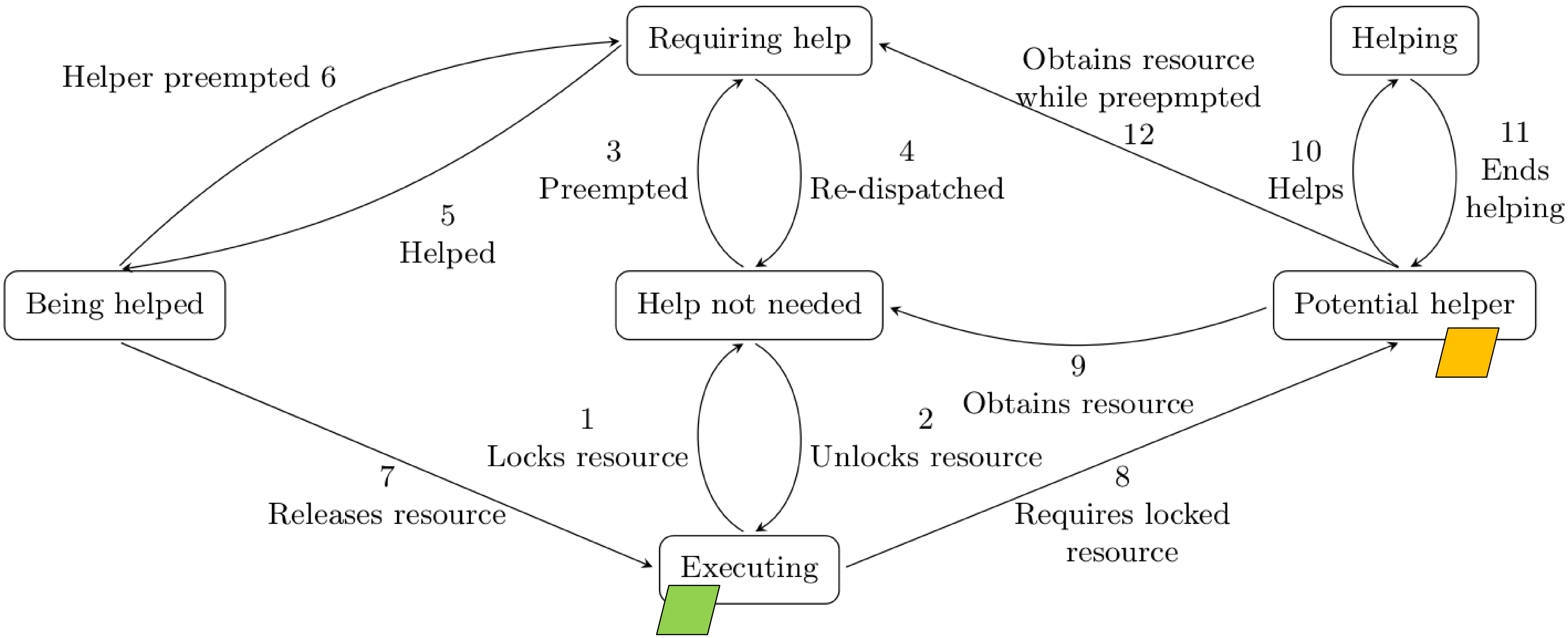
MrsP - Helping Mechanism



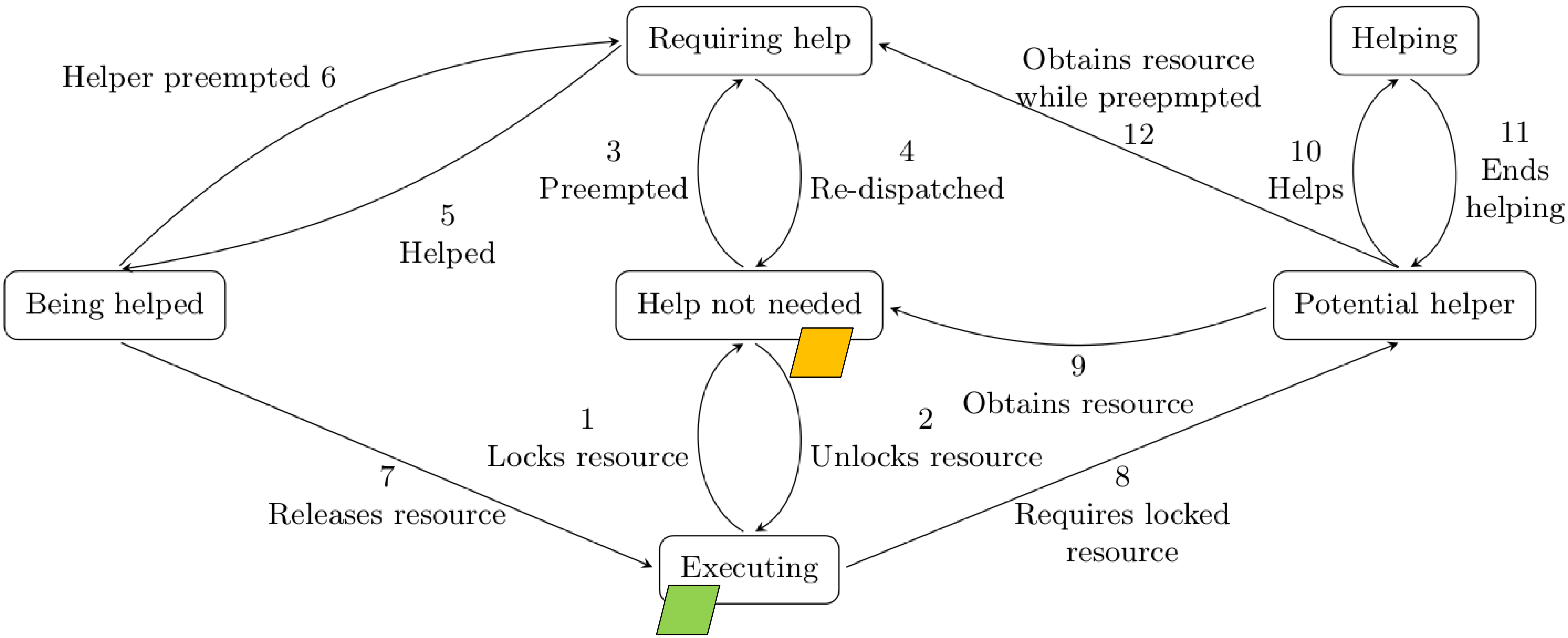
MrsP - Helping Mechanism



MrsP - Helping Mechanism



MrsP - Helping Mechanism



MrsP – Nested Model

- Challenges

MrsP – Nested Model

- Challenges
  - Global and Local resources

MrsP – Nested Model

- Challenges
  - Global and Local resources
  - Bound concurrency

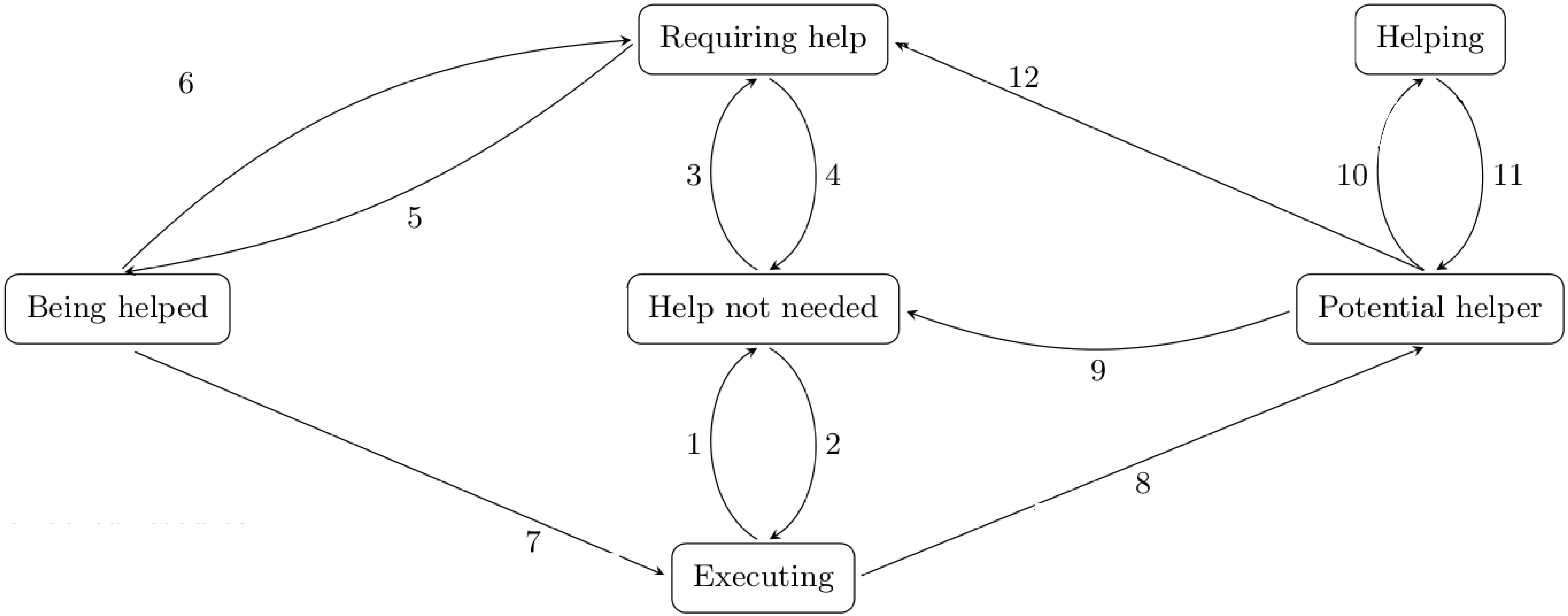
MrsP – Nested Model

- Challenges
  - Global and Local resources
  - Bound concurrency
  - Transitive blocking

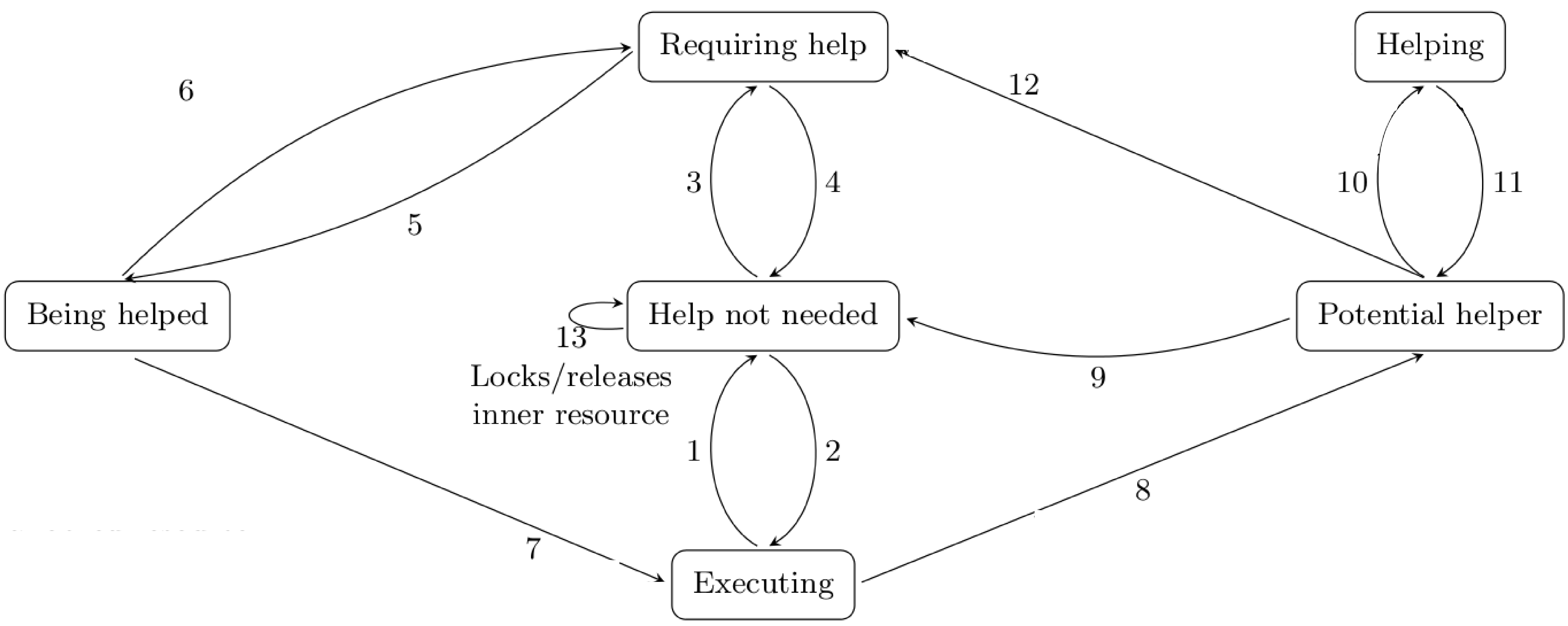
MrsP – Nested Model

- Challenges
  - Global and Local resources
  - Bound concurrency
  - Transitive blocking
  - Local blocking

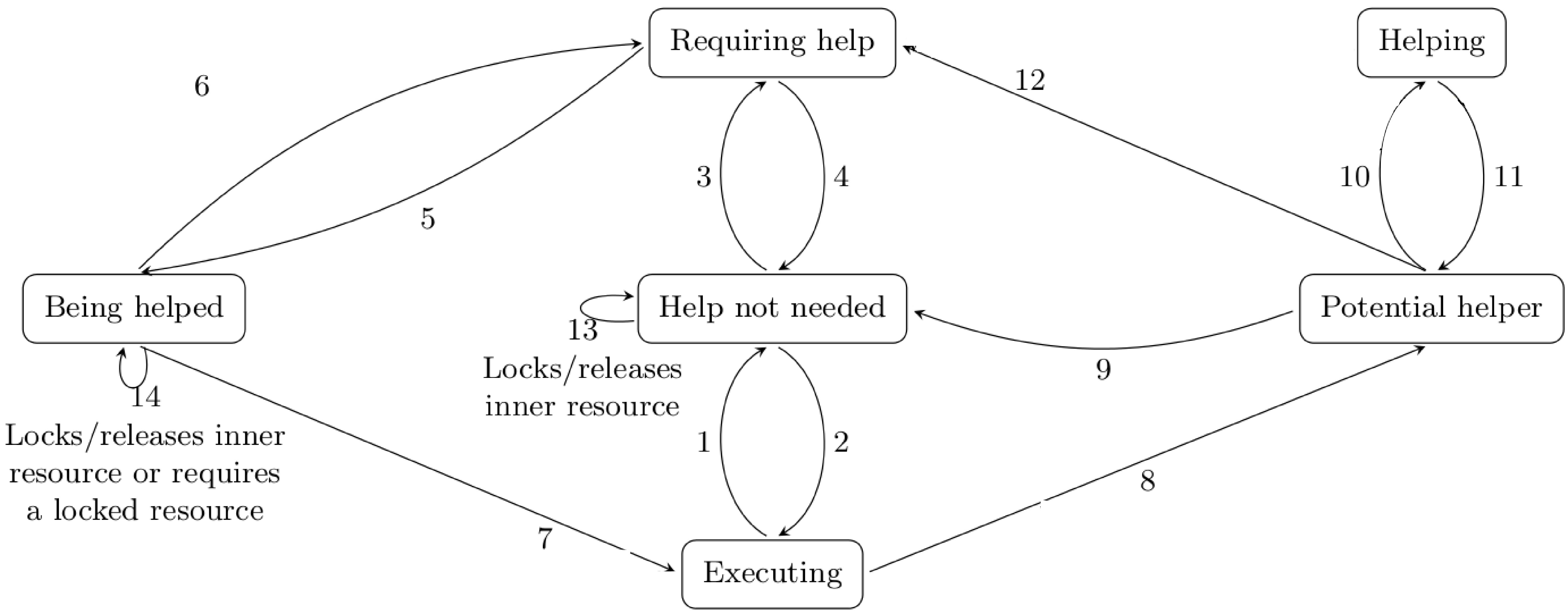
MrsP - Nested Helping Mechanism



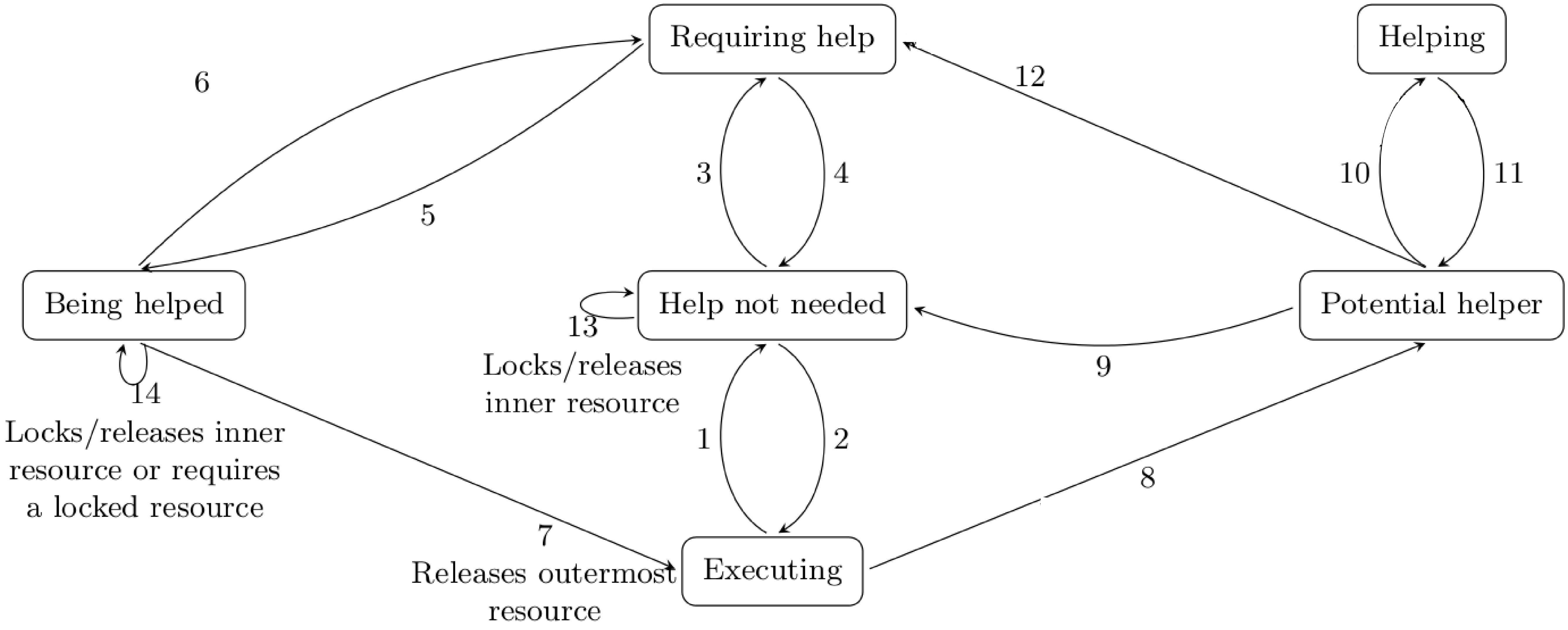
MrsP - Nested Helping Mechanism



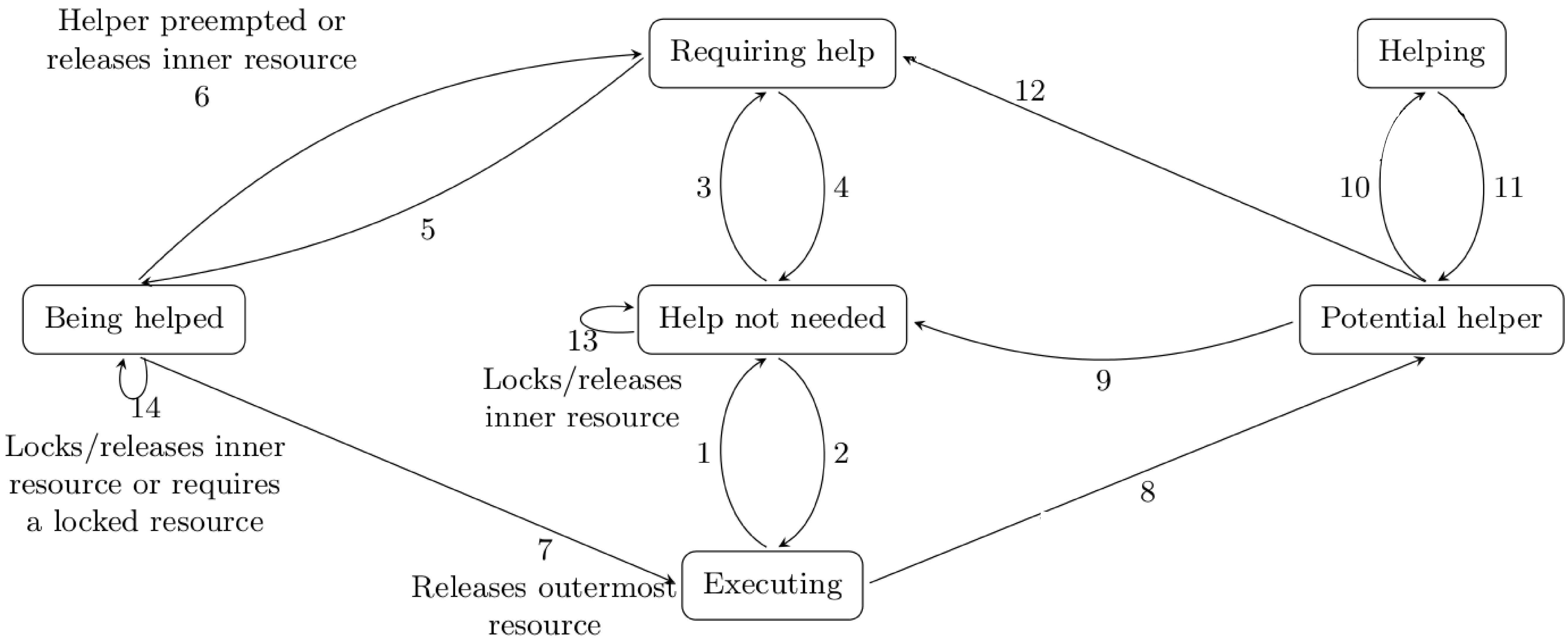
MrsP - Nested Helping Mechanism



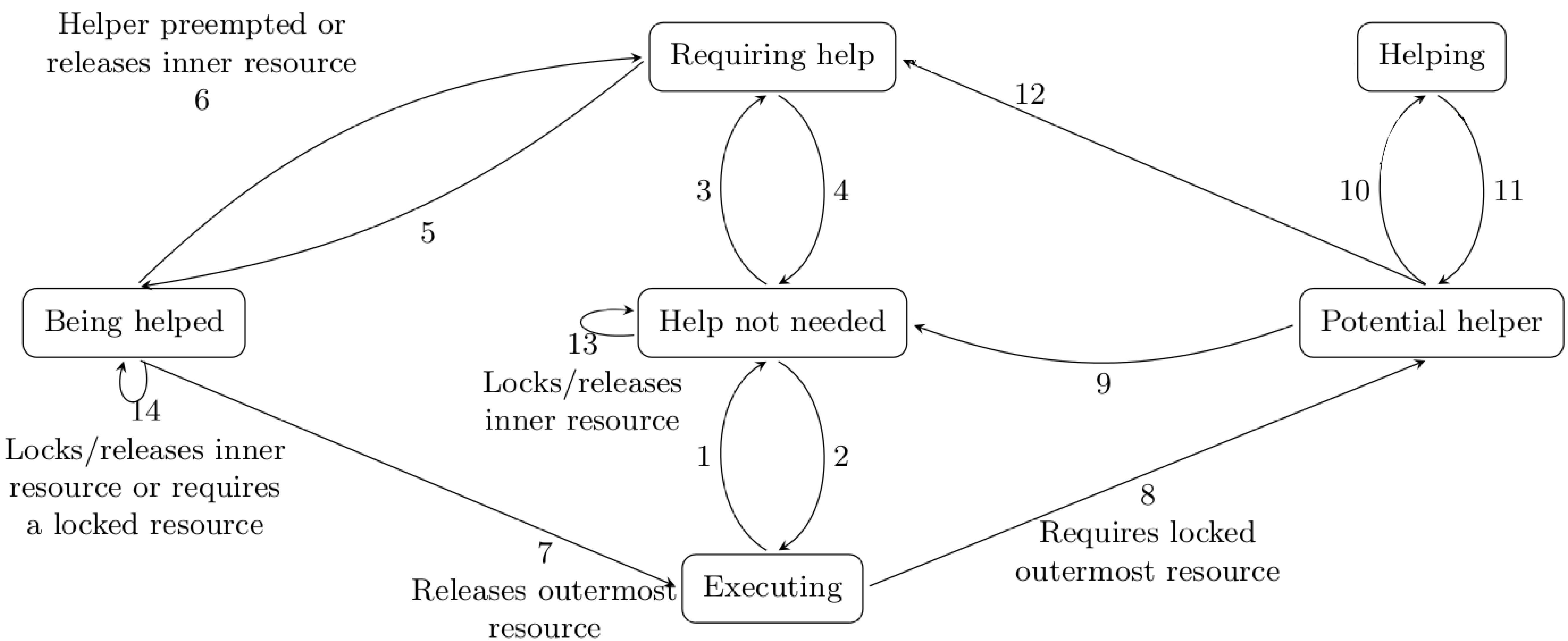
MrsP - Nested Helping Mechanism



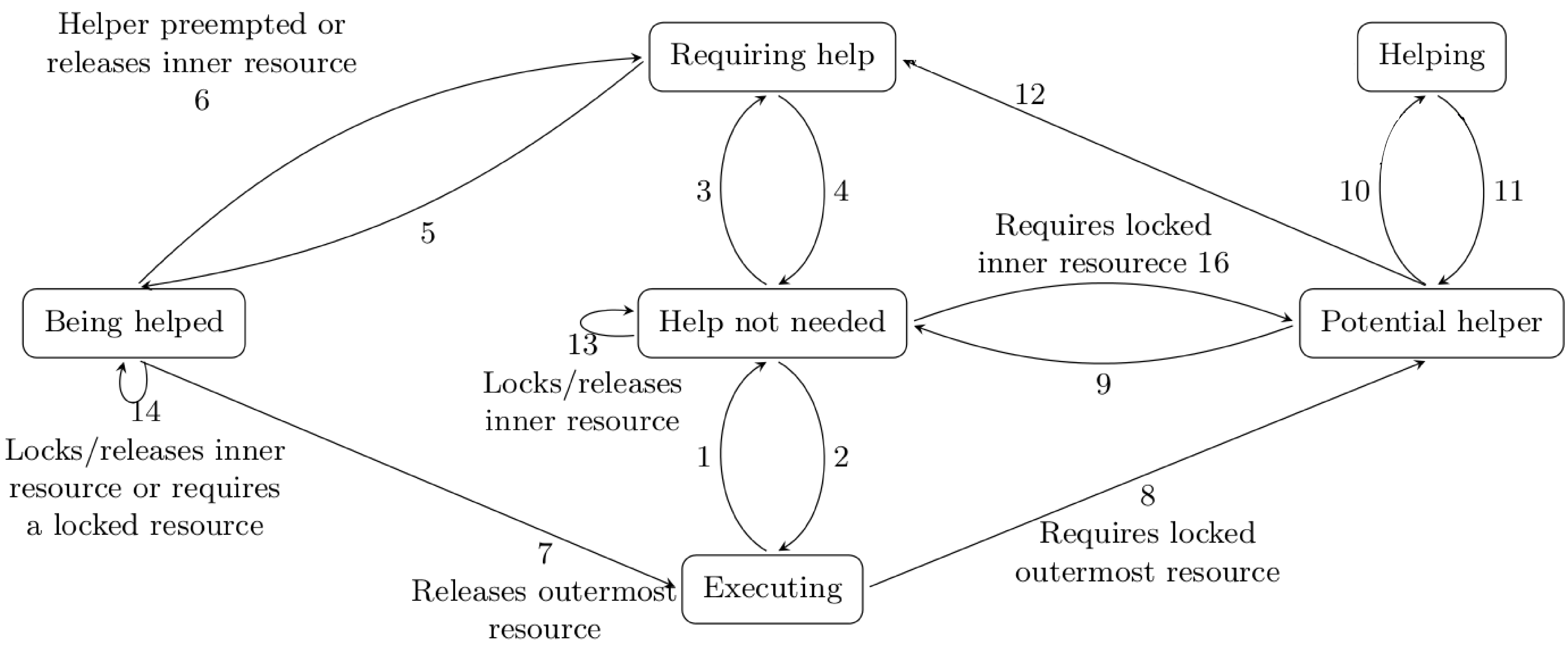
MrsP - Nested Helping Mechanism



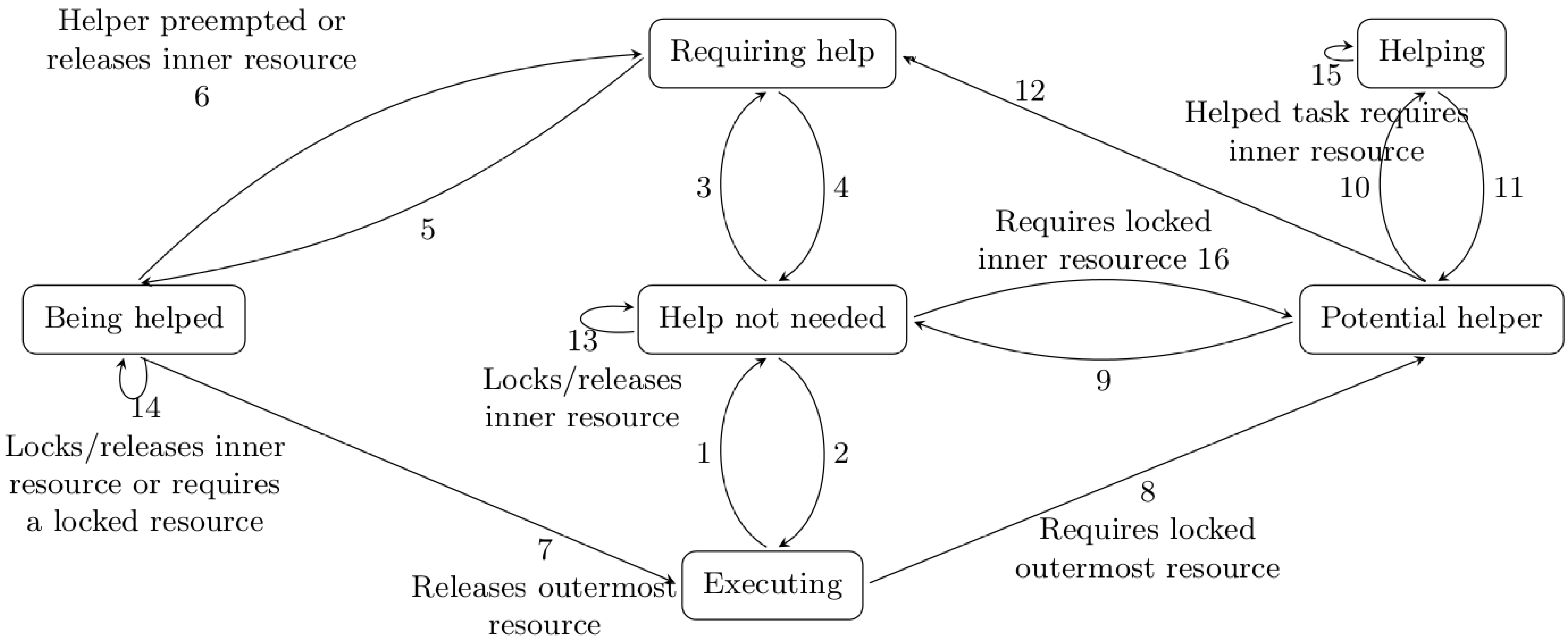
MrsP - Nested Helping Mechanism



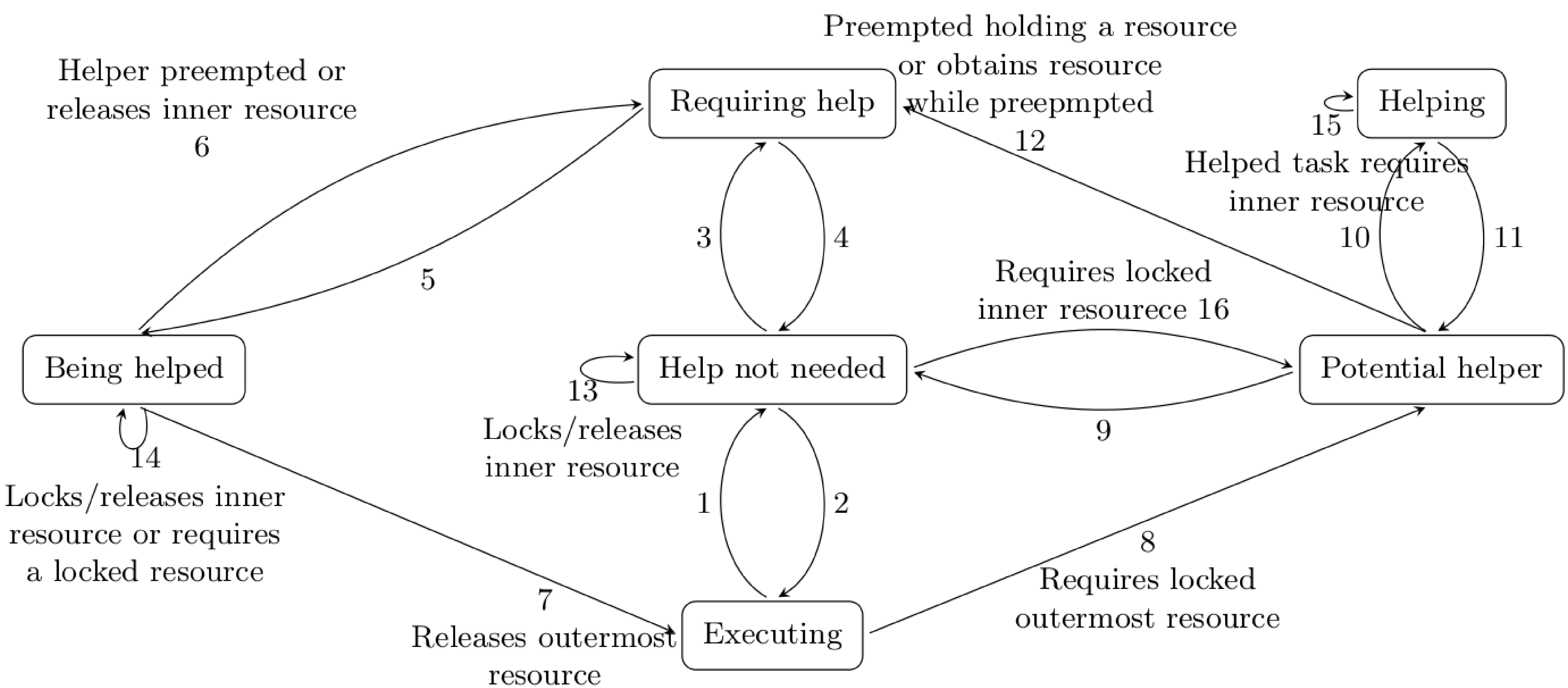
MrsP - Nested Helping Mechanism



MrsP - Nested Helping Mechanism



MrsP - Nested Helping Mechanism



MrsP - Nested Timing Analysis

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

MrsP - Nested Timing Analysis

$$e^j = \underbrace{(|V(r^j)| + |map(G(r^j))|)}_{\text{queue}} * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

- Access request sources:

MrsP - Nested Timing Analysis

$$e^j = \underbrace{(|V(r^j)| + |map(G(r^j))|)}_{\text{queue}} * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

- Access request sources:
  - Tasks request access from inside another resource

MrsP - Nested Timing Analysis

$$e^j = (|V(r^j)| + \underbrace{|map(G(r^j))|)}_{\text{queue}} * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

- Access request sources:
  - Tasks request access from inside another resource
  - Tasks not holding a resource

MrsP - Nested Timing Analysis

$$e^j = \underbrace{(|V(r^j)| + |map(G(r^j))|)}_{\text{queue}} * \underbrace{(c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)}_{\text{accessing time}}$$

- Access request sources:
  - Tasks request access from inside another resource
  - Tasks not holding a resource
- Access time:

MrsP - Nested Timing Analysis

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$\underbrace{(|V(r^j)| + |map(G(r^j))|)}_{\text{queue}} \quad \underbrace{(c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)}_{\text{accessing time}}$$

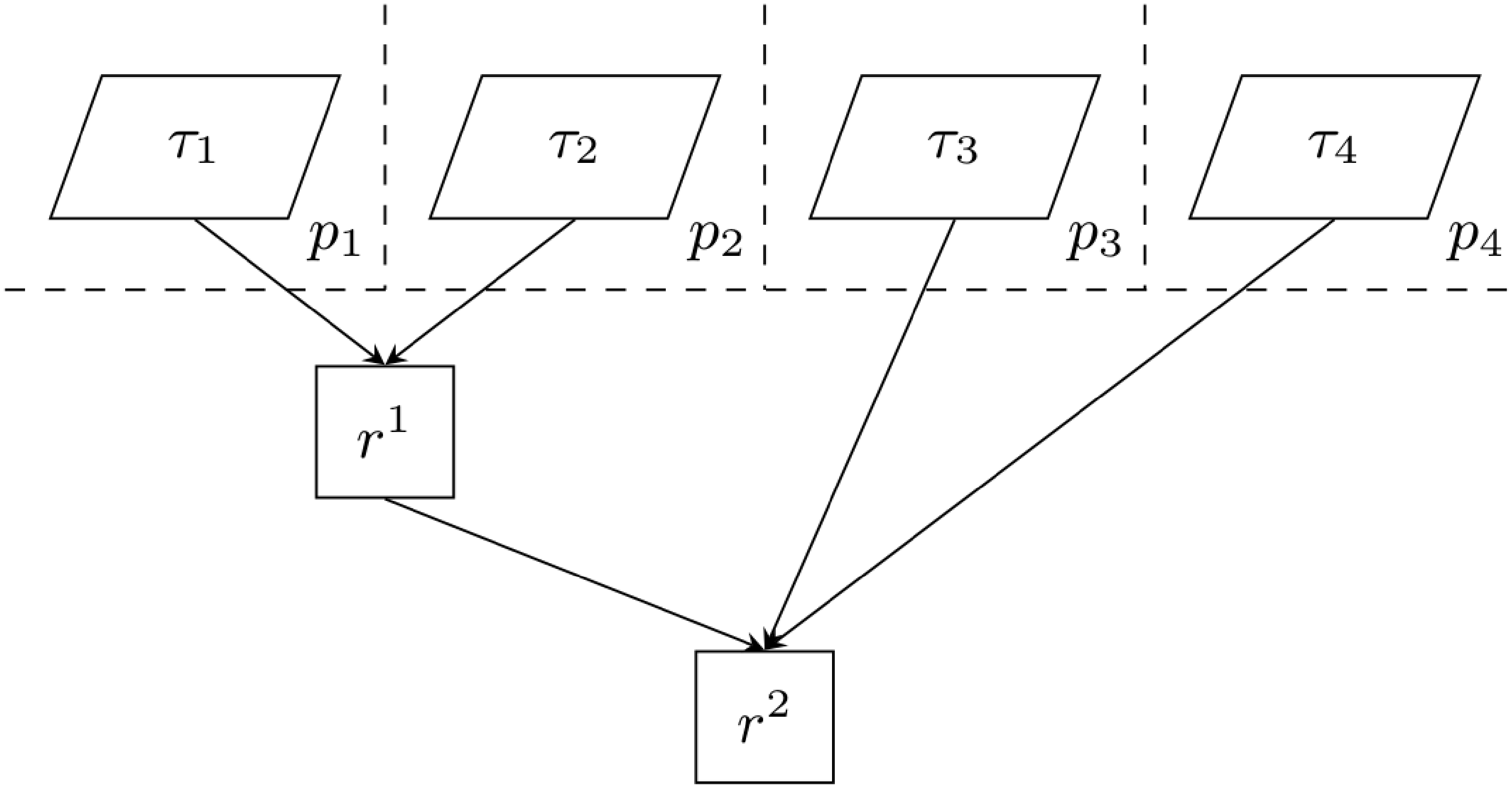
- Access request sources:
  - Tasks request access from inside another resource
  - Tasks not holding a resource
- Access time:
  - Resource execution time

MrsP - Nested Timing Analysis

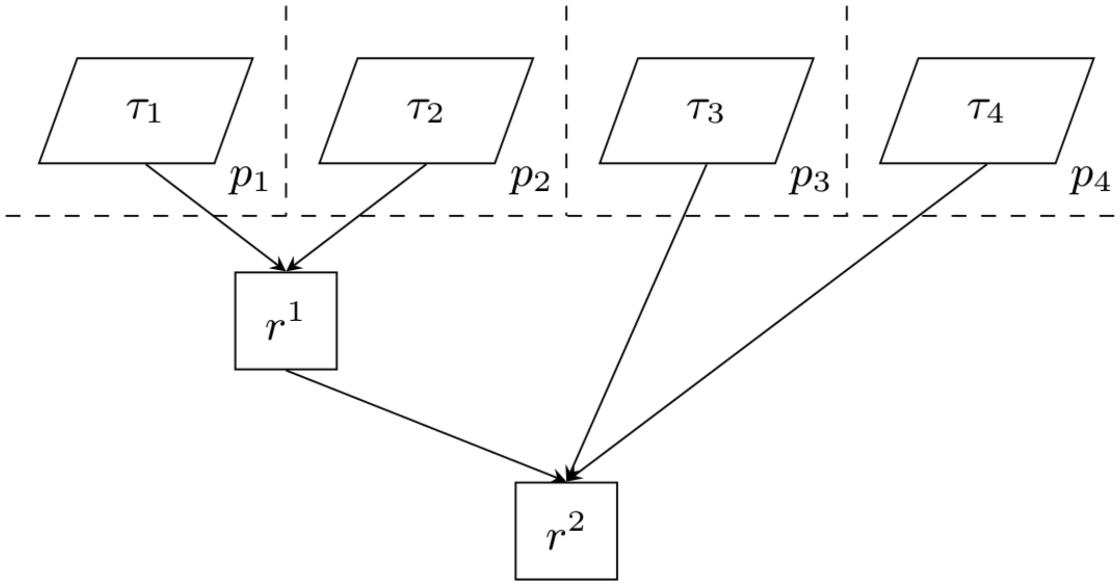
$$e^j = \underbrace{(|V(r^j)| + |map(G(r^j))|)}_{\text{queue}} * \underbrace{(c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)}_{\text{accessing time}}$$

- Access request sources:
  - Tasks request access from inside another resource
  - Tasks not holding a resource
- Access time:
  - Resource execution time
  - Inner resources access costs

Example



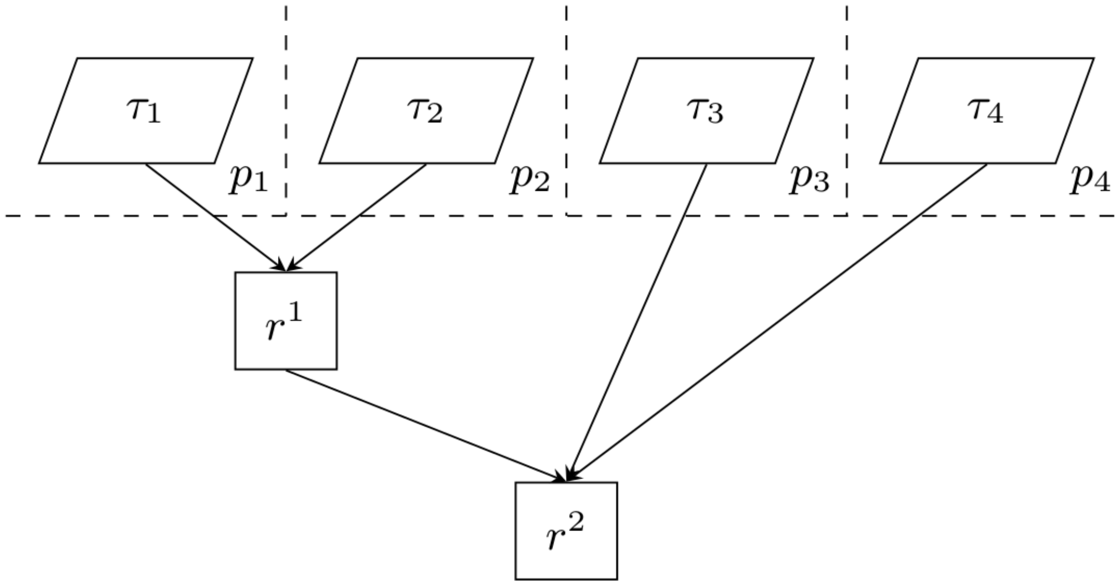
Example



Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

Example

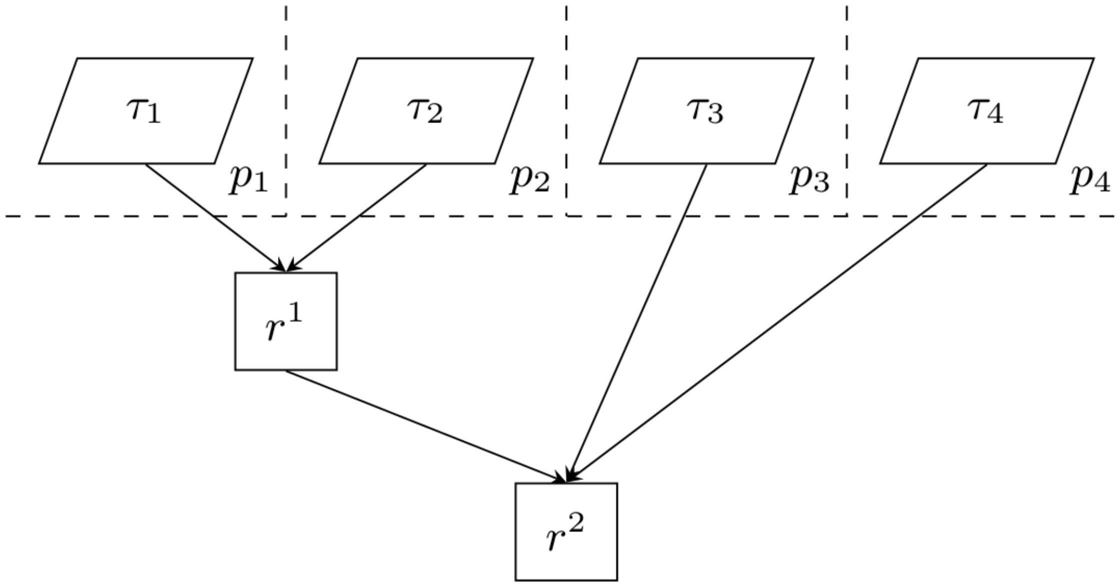


Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 =$$

Example

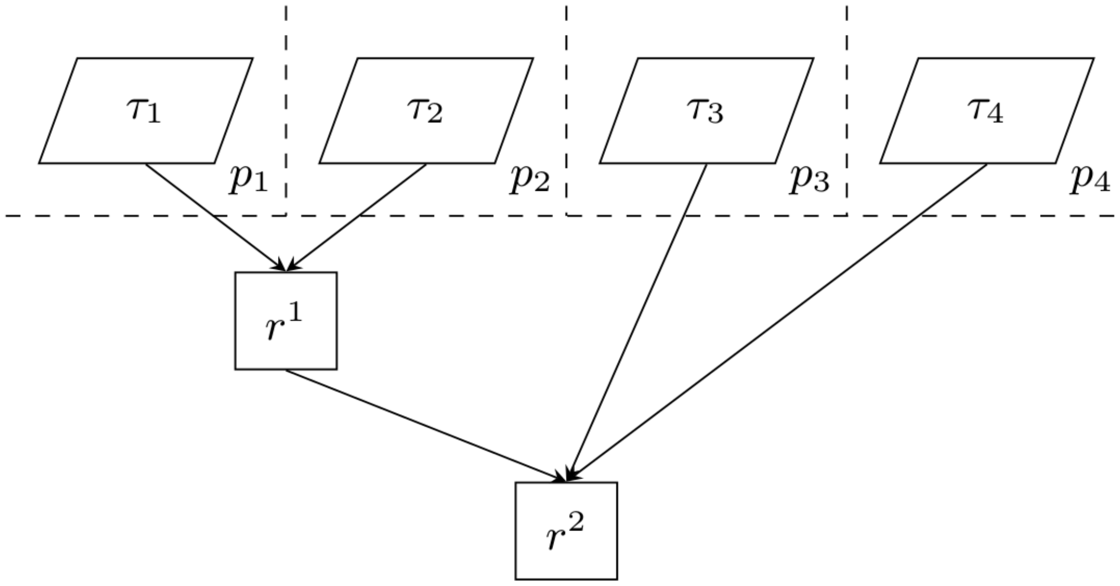


Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 +$$

Example

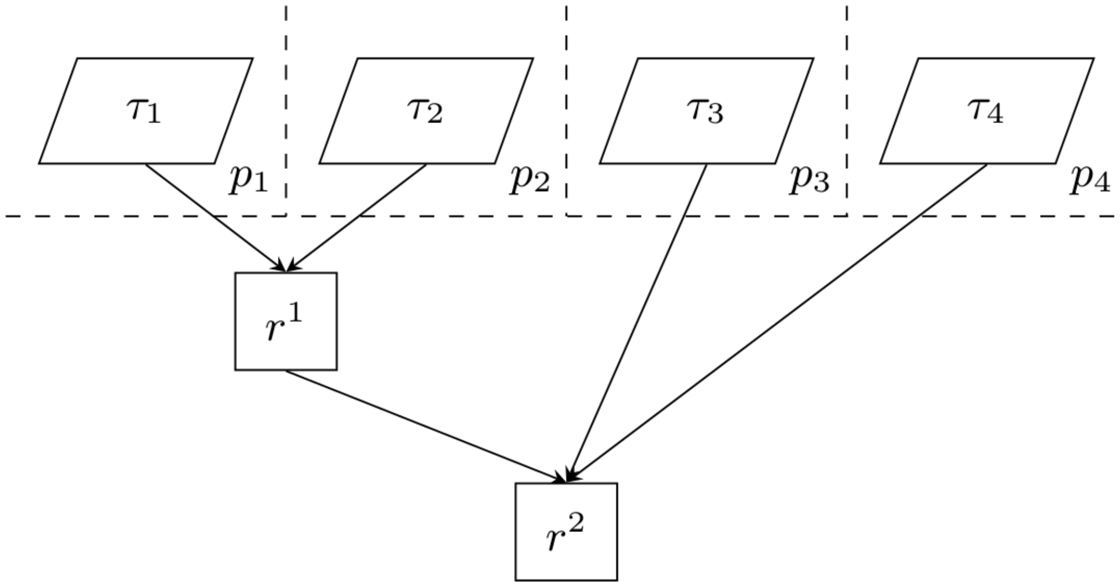


Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) *$$

Example

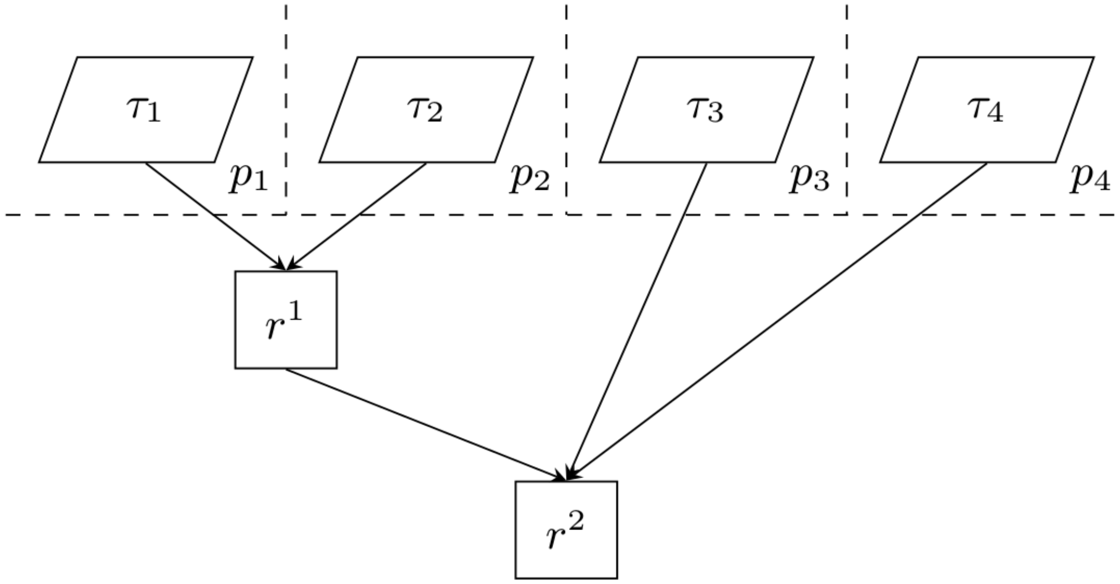


Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) =$$

Example

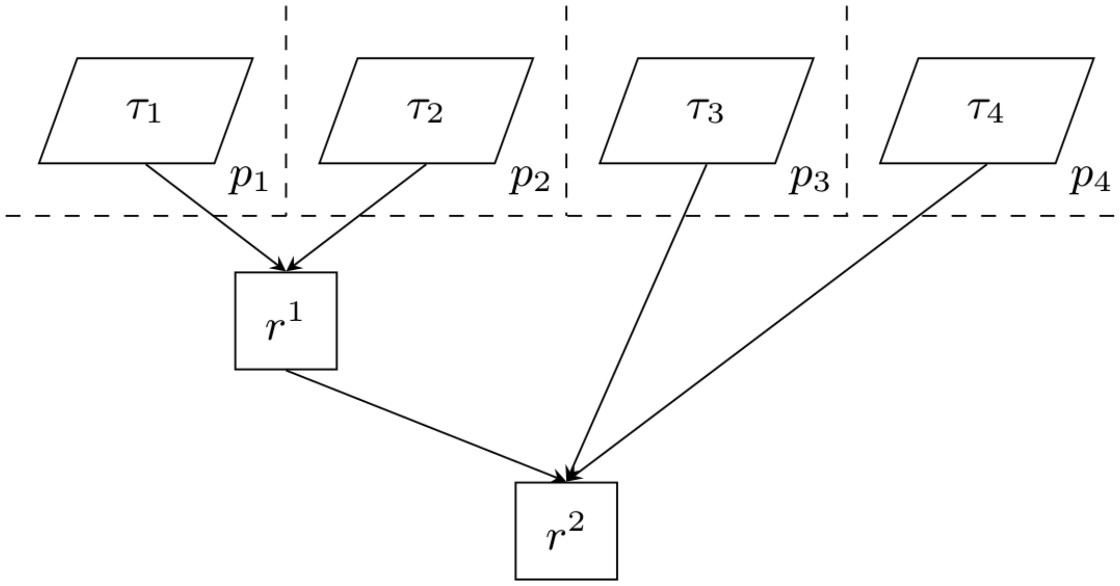


Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

Example



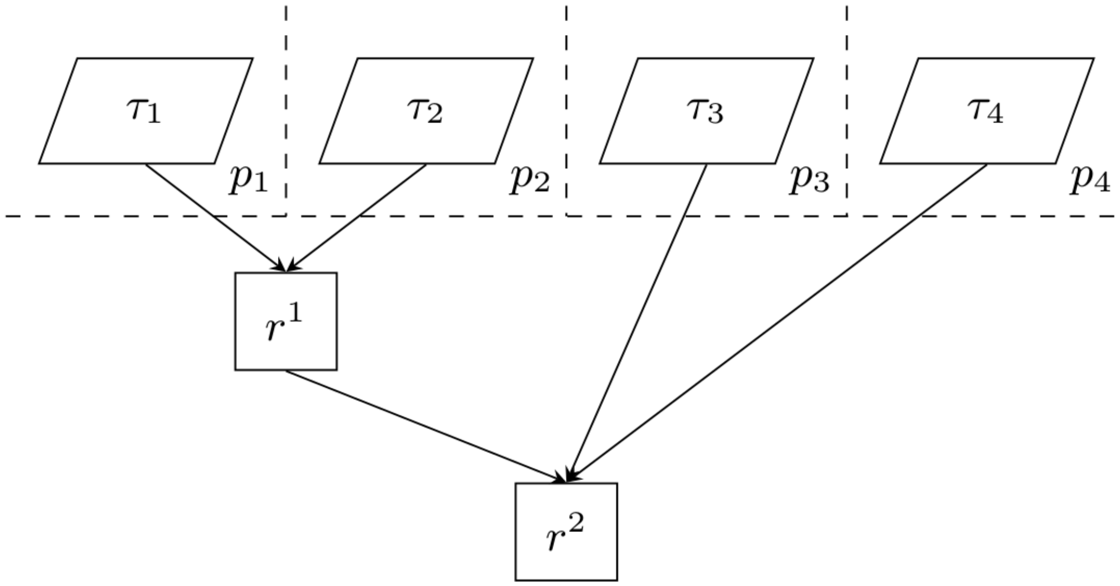
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 =$$

Example



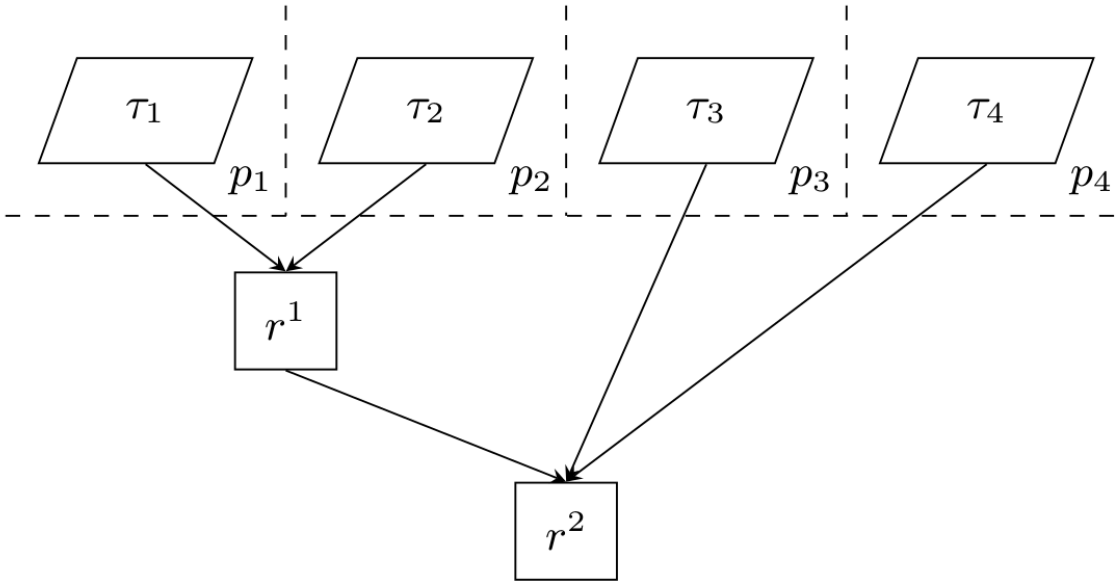
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 +$$

Example



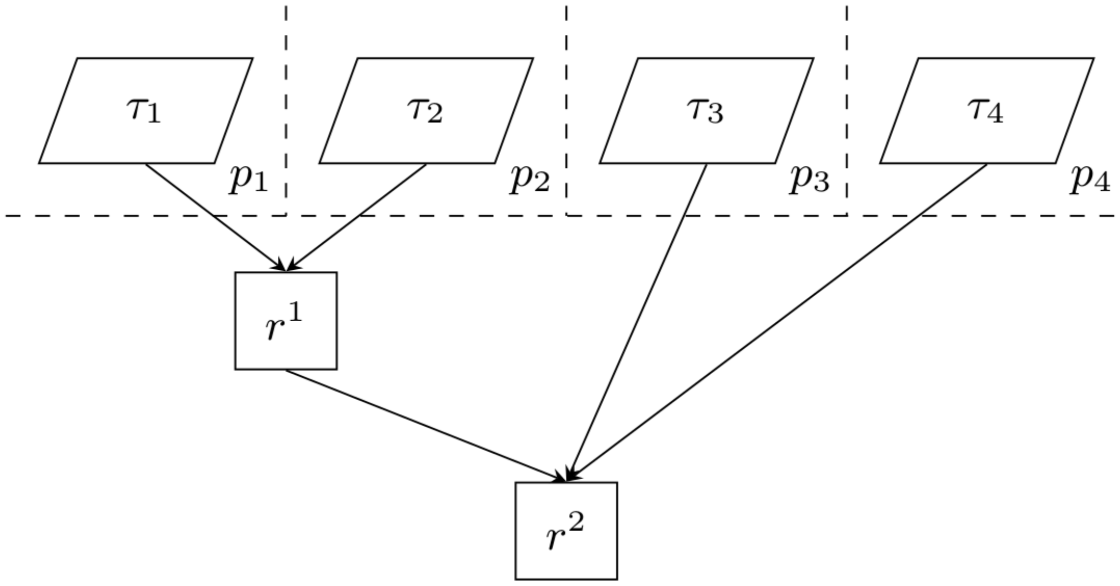
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 + 2) *$$

Example



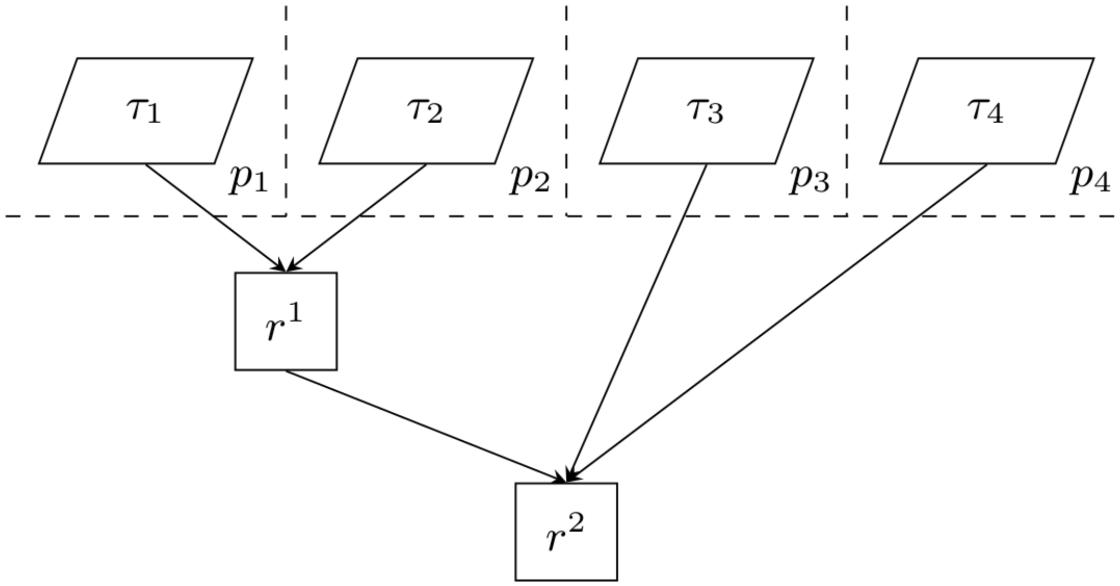
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 + 2) * (c^1 +$$

Example



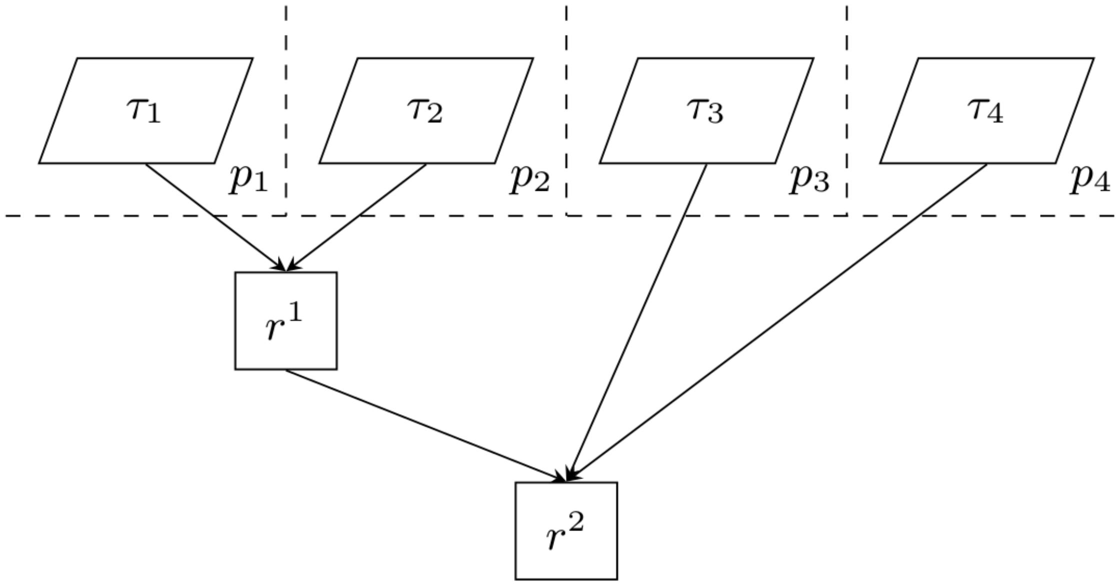
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 + 2) * (c^1 + e^2) =$$

Example



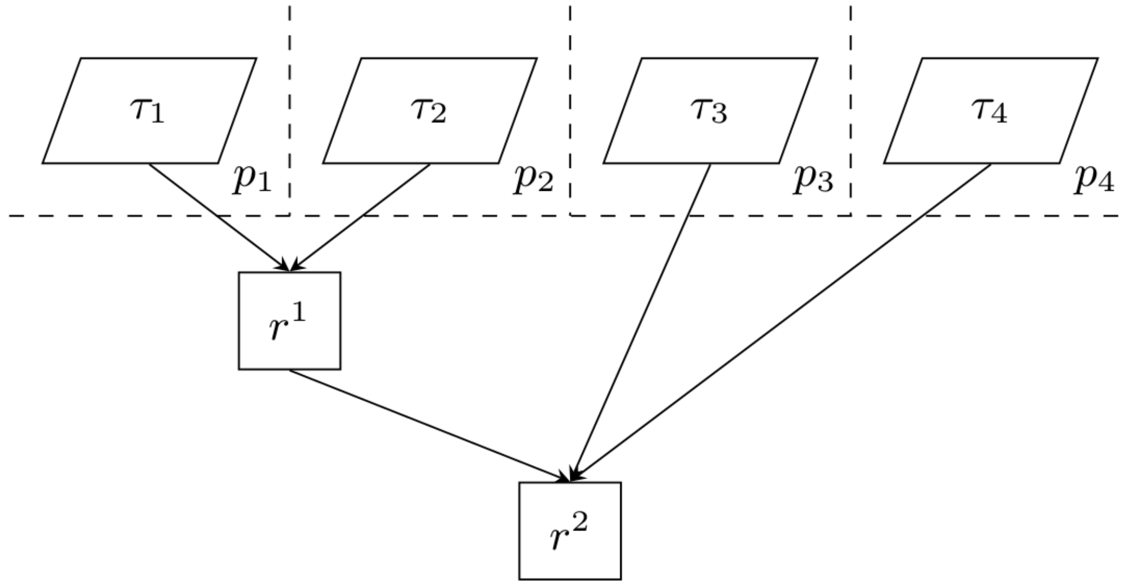
Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 + 2) * (c^1 + e^2) = 2(c^1 + e^2) =$$

Example



Resource	$G(r^i)$	$V(r^i)$	$map(G(r^i))$
r^1	τ_1, τ_2	$\emptyset$	p_1, p_2
r^2	τ_3, τ_4	r^1	p_3, p_4

$$e^j = (|V(r^j)| + |map(G(r^j))|) * (c^j + \sum_{r^k \in \mathbf{U}(r^j)} n_j^k e^k)$$

$$e^2 = (1 + 2) * (c^2) = 3c^2$$

$$e^1 = (0 + 2) * (c^1 + e^2) = 2(c^1 + e^2) = 2(c^1 + 3c^2)$$

MrsP – Nested Model

- Irreflexive partial order

MrsP – Nested Model

- Irreflexive partial order
- Helped task executes at helper active priority
  - Can be different to the held resource local priority

MrsP – Nested Model

- Irreflexive partial order
- Helped task executes at helper active priority
  - Can be different to the held resource local priority
- Tasks only update their priority on their own processor

MrsP – Nested Model

- Irreflexive partial order
- Helped task executes at helper active priority
  - Can be different to the held resource local priority
- Tasks only update their priority on their own processor
- Transitive helping mechanism
  - If t3 is waiting for t2, which waiting for t1, if the later are locally preempted, t3 helps t1

MrsP – Nested Model

- Irreflexive partial order
- Helped task executes at helper active priority
  - Can be different to the held resource local priority
- Tasks only update their priority on their own processor
- Transitive helping mechanism
  - If t3 is waiting for t2, which waiting for t1, if the later are locally preempted, t3 helps t1
- Tasks can help migrated local tasks

MrsP – Nested Model

- Irreflexive partial order
- Helped task executes at helper active priority
  - Can be different to the held resource local priority
- Tasks only update their priority on their own processor
- Transitive helping mechanism
  - If t3 is waiting for t2, which waiting for t1, if the later are locally preempted, t3 helps t1
- Tasks can help migrated local tasks
- Migrated tasks remain notionally dispatchable at host

MrsP – Conclusions

MrsP – Conclusions

- Provided full nested resource model to MrsP

MrsP – Conclusions

- Provided full nested resource model to MrsP
- Updated timing analysis

MrsP – Conclusions

- Provided full nested resource model to MrsP
- Updated timing analysis
  - Nested shared resource access cost bounded

MrsP – Conclusions

- Provided full nested resource model to MrsP
- Updated timing analysis
  - Nested shared resource access cost bounded
  - Fine grained analysis

Supporting nested resources in MrsP

Jorge Garrido
Universidad Politécnica de Madrid (UPM), Spain

Shuai Zhao
Alan Burns
Andy Wellings
University of York, UK