Enhancing Capabilities of Assistive Robotic Arms: Learning, Control, and Object Manipulation

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(ABSTRACT)

In this thesis, we explore methods to enable assistive robotic arms mounted on wheelchairs to assist disabled users with their daily activities. To effectively aid users, these robots must recognize a variety of tasks and provide intuitive control mechanisms. We focus on developing techniques that allow these assistive robots to learn diverse tasks, manipulate different types of objects, and simplify user control of these complex, high-dimensional systems.

This thesis is structured around three key contributions. First, we introduce a method for assistive robots to autonomously learn complex, high-dimensional behaviors in a given environment and map them to a low-dimensional joystick interface without human demonstrations. Through controlled experiments and a user study, we show that this approach outperforms systems based on human-demonstrated actions, leading to faster task completion compared to industry-standard baselines.

Second, we improve the efficiency of reinforcement learning for robotic manipulation tasks by introducing a waypoint-based algorithm. This approach frames task learning as a sequence of multi-armed bandit problems, where each bandit problem corresponds to a waypoint in the robot's trajectory. We introduce an approximate posterior sampling solution that builds the robot's motion one waypoint at a time. Our simulations and real-world experiments show that this approach achieves faster learning than state-of-the-art baselines.

Finally, to address the challenge of manipulating a variety of objects, we introduce RIgid-SOft (RISO) grippers that combine soft-switchable adhesives with standard rigid grippers

and propose a shared control framework that automates part of the grasping process. The RISO grippers allow users to manipulate objects using either rigid or soft grasps, depending on the task. Our user study reveals that, with the shared control framework and RISO grippers, users were able to grasp and manipulate a wide range of household objects effectively. The findings from this research emphasize the importance of integrating advanced learning algorithms and control strategies to improve the capabilities of assistive robots in helping users with their daily activities. By exploring different directions within the domain of assistive robotics, this thesis contributes to the development of methods that enhance the overall functionality of assistive robotic arms.

Enhancing Capabilities of Assistive Robotic Arms: Learning, Control, and Object Manipulation

Shaunak A. Mehta

(GENERAL AUDIENCE ABSTRACT)

In this thesis, we explore ways to make robotic arms attached to wheelchairs more helpful for people with disabilities in their everyday lives. To be truly useful, these robots need to understand a variety of tasks and be easy for users to control. Our focus is on developing techniques that help these robots learn different tasks, handle different types of objects, and make controlling them simpler.

The thesis is built around three main contributions. First, we introduce a way for robots to learn how to perform complex tasks on their own and then simplify controlling robots for those tasks so users can control the robot to perform different tasks using just a joystick. We show through experiments that this approach helps people complete tasks faster than systems that rely on human-taught actions.

Second, we improve how robots learn to perform tasks using a more efficient learning method. This method breaks down tasks into smaller steps, and the robot learns how to move toward each step more quickly. Our tests show that this approach speeds up the learning process compared to other methods.

Finally, we address the challenge of handling different types of objects by developing a new type of robotic gripper that combines soft and rigid gripping options. This gripper allows users to pick up and manipulate a wide variety of household objects more easily, thanks to a control system that helps automate part of the process. In our user study, people found it easier to use the new gripper to handle different items.

Overall, this research highlights the importance of combining learning algorithms and user-friendly controls to make assistive robots better at helping people with their daily tasks. These contributions advance the development of robotic arms that can more effectively assist users.

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I am incredibly fortunate to have received the support of so many people on this journey, and I am deeply grateful for their contributions, which have made reaching this stage possible. First and foremost, I would like to express my sincere gratitude to my advisor, Dr. Dylan P. Losey, for his unwavering guidance and invaluable research insights, without which this thesis would not have been possible. I am also deeply thankful to my committee members, Dr. Michael D. Bartlett and Dr. Kaveh Akbari Hamed, for their time, effort, and insightful feedback that significantly enriched this work. A heartfelt thank you to my labmates — Ananth, Soheil, Sagar, Shahab, Ben, Josh, and Maya — for the countless brainstorming sessions, support, and camaraderie during social events that helped me navigate this stage of life. I owe a profound debt of gratitude to my family, especially my parents, grandmother, and the cherished memory of my late grandfather. Their unwavering love, hard work, and constant support have been the foundation upon which I stand today. Lastly, I extend my deepest thanks to my roommates and friends, whose companionship and encouragement kept me motivated and reach the end of this wonderful journey.

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3.1 Human teleoperating an assistive robot arm. We hypothesize that assistive robots can learn useful teleoperation mappings without human supervision by optimizing for high-entropy and object-related behaviors, and then embedding those diverse actions into a user-controlled latent space. Here the robot autonomously learns to map the user's joystick inputs to dexterous, coordinated motions that reach for the cup or open the drawer. 11

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3.3 Simulated human controlling the Panda robot arm with learned latent actions. We compare latent actions trained on human-provided kinesthetic demonstrations (b_j0 §\0§_H) and teleoperated demonstrations (¦0e0nq) to our unsupervised approach (m«}). We also consider ¦0e0nq as the participants' demonstrations become increasingly noisy and imperfect (= 0:01, = 0:1). m«} outperforms b_j0 §\0§_H and noisy versions of ¦0e0nq, and is slightly worse than ¦0e0nq (= 0:0). Our method enables the robot to match prior latent action approaches without requiring any human demonstrations. . . . 19

3.4 Follow-up experiment where we initialize our approach with human demonstrations (m«} v ¦0e0nq). These demonstrations help our approach avoid local minima (i.e., only reaching two cups), and our approach improves the demonstrations by optimizing for other high-entropy behaviors. 24

3.5 Task and results from our user study. Participants teleoperated the robot arm to remove clutter (objects 1 and 2), pull the bowl closer to their person (3), pick up the container (4) and pour it into the bowl, and finally drop the container in the bin (5). We compare our unsupervised approach (where participants interact with one joystick) to direct end-effector control (where participants can use two joysticks and toggle between two modes). Participants completed the task more quickly with our approach, but their subjective responses were mixed. Here denotes $p < .05$ and denotes $p < .07$. 25

4.1 Our waypoint-based approach for model-free reinforcement learning in manipulation tasks. The robot arm learns where to place the next waypoint to maximize its reward by solving a multi-armed bandit. We then freeze the learned models for waypoint i, and repeat the process for waypoint $i+1$. This approach learns the desired task across a distribution of initial states; i.e., the location and angle of the drawers can change at each interaction. 30

4.2 Simulation environments and rewards for six manipulation tasks. These benchmark tasks are taken from robosuite [1]. For each task the image on the left shows the environment setup, and the plot on the right shows the robot's rewards averaged over five runs. Higher rewards indicate better task performance. The dashed lines in the reward plots correspond to the episodes where m«} approach added a new waypoint to the trajectory. Adding these new waypoints often causes a sharp increase in the robot's reward. This sudden change occurs because the new waypoint enables the robot to complete the next part of the task: e.g., in *d_I§* the robot needs one waypoint to grasp the block and a second waypoint to lift the block. 45

4.3 Setup and results from our real-world experiments in Section 4.5. In *d_T§* the robot learned to pick up an item, and in *K}9°0}* it learned to open a drawer (also see Figure 4.1). The robot measured the initial position of the item or drawer as a part of the start state s^0. ~8G learned a policy that often moved to the object of interest, but did not correctly interact with that object. When using m«} , the robot built a trajectory of two waypoints: the first waypoint grasped the object, and then the second waypoint interacted with that object (e.g., picked the item up, pulled the drawer open). The dashed line in the reward plots corresponds to the episode where m«} robot added a second waypoint to its trajectory. 49

5.1 Human controlling an assistive robot arm and RIgid-SOft (RISO) gripper. The RISO gripper is formed by mounting soft, switchable adhesives to the bottom of a rigid, industry-standard, parallel mechanism. Using RISO grippers robot arms can pick up large, rigid items (e.g., a jar of mustard) as well as small, numerous, and fragile objects (e.g., a pile of candy). 52

5.2 Moving small, numerous objects with an industry-standard rigid gripper [2] and our proposed RISO gripper. The robot was tasked with carrying 15 M&M's from piles on the right side of the table to a plate on the left side of the table. (Top) Using the standard rigid gripper the robot was only able to move one item per interaction. (Bottom) By contrast, the RISO gripper could pick up, hold, and release multiple small candies during each interaction. 53

5.3 Soft switchable adhesives used in the RISO gripper. (a) Active membrane-foundation adhesives composed of a polydimethylsiloxane (PDMS) substrate, a foam layer, and then a PDMS membrane. We attach these adhesives to the bottom of the rigid gripper using 3D printed mounts. (b – e) Grasping and releasing an object. For grasping, negative chamber pressures ($P < 0$) deflate the membrane and cause the object to adhere to the foam foundation. For releasing, positive pressures ($P > 0$) inflate the membrane and decrease the contact area, reducing the adhesion force. 55

5.4 Pneumatic control setup for the RISO gripper's soft adhesives. (Left) The pressure regulator inlet (P_{in}) is connected to a supply pressure of 5-10 Psi, and the exhaust is connected to a vacuum pump. The pressure P of the output chamber ranges from 13 to +2:9 Psi. (Right) Adhesion force increases as we decrease P from positive to negative values. The robot arm communicates with the pressure regulator to set P in real-time. 57

5.5 RISO gripper picking up example objects from our user study. The first column demonstrates the use of the rigid mechanism, while columns 2-6 highlight the soft adhesives. (Top Row) Images of the RISO gripper holding items. (Bottom Row) 10 participants controlled the robot to try and grasp these items using [« h 9 j Gn j §}ne and ~\9}0L Gn j §}ne. We plot the average success per item across all users (i.e., the percentage of time that users were able to pick up the target item). Success was comparable for [« h 9 j and ~\9}0L when grasping an object using the rigid gripper (column 1). However, ~\9}0L outperformed [« h 9 j when participants attempted to leverage the soft adhesives (columns 2-6). 63

5.6 Objective results from our user study. During this study we placed 15 household items on a table, and participants controlled the robot arm and RISO gripper to pick up each object and drop it in a bin. We compared two control approaches: [« h 9 j Gn j §}ne, where the user teleoperated each step of the process, and ~\9}0L Gn j §}ne, where the autonomous robot helped to align the RISO gripper for the human's target object and grasp type. ~\9}0L Gn j §}ne led to a higher overall success rate (~«HH0), less time spent picking up objects (W}9 q ¦_h0), less robot motion (W}9 q K_ §9jH0), and users spent less time interacting with the joystick (^jq«§ ¦_h0). Error bars show standard error and an denotes statistical significance ($p < .05$). 67

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4.1 Evaluation results. After training in Figure 4.2, we saved the learned models and evaluated their performance across 100 episodes. We report average reward standard error. 46

5.1 Percentage of interactions where participants successfully picked up, moved, and released each object in the user study. For the top three objects we instructed participants to leverage the rigid gripper; participants used the soft adhesive for the remaining items. 68

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Robots have increasingly become integral to modern life, with their applications extending far beyond traditional manufacturing environments into more interactive settings such as healthcare and household settings. The advancements in robotic technology, particularly in the fields of artificial intelligence and machine learning, have enabled robots to transition from being purely industrial tools to becoming sophisticated systems capable of interacting with humans and assisting them in meaningful ways. In these domains, teleoperated and assistive robotic arms are now employed for a range of tasks, including surgical procedures [3], rehabilitation [4, 5], elder care [6], and assistance with daily activities such as cleaning, cooking, and organizing [7, 8]. Over one million adults living in America suffer from physical disabilities and rely on caregivers to perform their daily activities [9].

Wheelchair-mounted robotic arms hold significant potential to assist users with performing everyday tasks, thereby reducing their dependence on caregivers, especially in household activities such as cooking, table setting, and cleaning. One key challenge in this domain lies in the control of these robotic arms. Industry-standard wheelchair-mounted arms are typically operated using a 2-degree-of-freedom (DoF) joystick, which users can manipulate to control the robot arm's movements [10]. However, controlling a high-dimensional robotic arm with a low-dimensional input device like a 2-DoF joystick is inherently challenging. Users are often required to switch between different modes on the joystick to manage various aspects of the robot's movement. For example, one mode might control movement in the x-y plane, while

another controls movement along the z axis and the arm's roll orientation. If the assistive robotic arm could perceive the environment and recognize the user's intended task, it could intelligently map the joystick inputs directly to specific tasks. This would enable users to perform complex actions, such as manipulating objects in the environment, with minimal input, potentially requiring just a single axis of joystick control. Recent research has explored the possibility of learning such teleoperation mappings, where low-dimensional joystick inputs are translated into high-dimensional, task-specific robot actions [11, 12]. However, these approaches typically require a non-disabled individual or caregiver to provide task-specific demonstrations in the environment, from which the robot learns to map tasks to latent actions in a low-dimensional space. This reliance on a caregiver or expert for demonstrations conflicts with the primary goal of reducing the dependence of disabled individuals on others. One potential solution involves model-free learning techniques such as reinforcement learning (RL) [13]. In this approach, the robot learns a policy to accomplish various tasks based on predefined reward functions and then uses this policy to collect task-specific demonstrations through multiple rollouts. While this method reduces the need for caregiver involvement, it can be time-consuming, particularly when training in a new environment, as it requires significant time to converge on effective task-specific policies.

Another major challenge in the use of assistive robots is enabling the robots to grasp an manipulate diverse sets of objects in the environments ranging from small delicate items such as candies to large heavy items such as a jar of mustard. The wheelchair mounted assistive arms are generally equipped with industry standard rigid grippers [2, 14]. While these grippers are effective for manipulating large and heavy objects, they often struggle with manipulation of small and delicate objects. Recent advancements in soft robotic grippers have shown promise in handling such delicate objects [15, 16, 17]. However, unlike their rigid counterparts, soft grippers face limitations in manipulating large, heavy items. This

highlights the need for a versatile gripper that is capable of manipulating a diverse set of objects.

In this thesis, we explore how robots can learn effective teleoperation mapping to assist disabled users with the tasks of daily living that involve interacting with a diverse range of objects. We are primarily focused on teaching robots to recognize the environment and the task a user intends to perform and providing assistance in executing these tasks from low-dimensional control inputs provided by the user. Overall, our contribution in this thesis is three-fold:

dO9}j_jX d9§Oj§ 8H§_nj °_§\n«§ [«h9j KOhnj §}9§_nj u In Chapter 3, we propose a two-step approach to train a robot to perform diverse behaviors in the environment by maximizing the object state entropy, followed by using an autoencoder to embed the learned diverse behaviors into a low-dimensional latent space that can be leveraged by the users to control the robot. We compare our proposed approach to latent actions learned with human demonstrations. We show that latent actions learned using our proposed approach lead to more successful task completion, particularly if the human demonstrations are noisy. Finally, we conduct an in-person user study where non-disabled participants teleoperate a robot arm using our proposed approach and an industry standard teleoperation baseline. Our results show that using our proposed approach reduces the overall task completion time for the users. This work has been published in [18].

¯9´qn_j§]?9 OL |O_jTn}HOhOj§ dO9}j_jX Tn} |n@n§ g9j_q«e9§_nj ¦9 c u In Chapter 4, we focus on improving the learning efficiency of the reinforcement learning algorithms. To that end, we use waypoints to formulate the model-free reinforcement learning problem as a sequence of multi-armed bandits, where each bandit problem corresponds to one waypoint along the robot's trajectory. We theoretically demonstrate that this approach has lower regret bounds than the existing reinforcement learning frameworks. We intro-

duce an algorithm that approximately solves the sequence of multi-armed bandits through posterior sampling. In simulated benchmark environments and real world experiments, we show that our proposed approach leads to higher rewards and faster learning as compared to state-of-the-art baselines. This work has been published in [19].

| ^~mI Gn h @_j_j X | _X_L W}_q q0} °_§\ ~nT§ ~ °_§H\9@e0 8L\0 _®0 u In Chapter 5, we introduce RIgid-SOft (RISO) grippers by attaching a novel class of soft switchable adhesives to the bottom of industry standard grippers. When using the RISO gripper, the users may leverage the rigid mechanism or the soft switchable adhesives to perform grasps. This results is additional complexities when controlling a high-dimensional robot arm. Accordingly, we formulate a shared control approach for the RISO grippers. We test the performance of the RISO gripper and the shared control algorithm in an in-person user study, where the users had to manipulate a diverse set of household objects. We compare the gripper's performance when it is fully teleoperated by the users and when it uses our shared control approach. Our shared control approach leads to a lower human effort while achieving a higher success rate in object grasping. This works has been published in [20].

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8e)X Hi2`M iBp2Hv- BM Qi?2` rQ`Fb KQ i?2 +?H M2bBM2/7;BQM Hb- M
`2BM7Q`+2K2Mi H2 `MBM; 2 Mi2Q2Ti2 K2BM?2b2 BMi2`K2/B i2 ;Q Hb 7Q` i
(8d8 3)X S`BQ` `2b2 `+? bm;;2bib i? i i?Bb +QK#BM iBQM Q7 KQiBQM
H2 `MBM; Bb 2772+iBp2 7Q` HQM;@?Q`BxQM i bFb r?2`2 i?2 `Q#
bT2+B7B+ bi i2b U2X;X- iQ TB+F mT #HQ+F- i?2 `Q#Qi Kmbi 7B`b
i? i #HQ+FVX

SQbi2`BQ` a KTHBM; 7Q` _2BM7Q`+2K2MFi2G22`b2TM2Xp BQmb TT`
r2 rBHH 7Q`KmH i2 i?2 T`Q#H2K Q7 H2 `MBM; i?2 `Q#Qiöb i` D2
`K2/ # M/Bib- r?2`2 2 +? # M/Bi +Q``2bTQM/b iQ r vTQBMiX PM
bQHpBM; KmHiB@ `K2/ # M/Bib Bb TQbi2`BQ` b KTHBM; ? b T`2pBQmbHv #22M 2ti2M/2/ iQ `2BM7Q`+2K2M
#QmM/b BM /Bb+`2i2 bi i2 bQ`2 +?2Bb(b K2 TT`Q +? Bb MQ
BM +QMiBMmQmb- ?B;?@/BK2MbBQM H 2MpB`QMK2MibX AMbi2
+m` i2 TT`QtBK iBQMb mbBM; M2m` H 2MibQ`Q#H2?2i`K2/MiQB/2HbM
(eRe)X q2 rBHH bBKBH `Hv H2p2` ;2 M 2Mb2K#H2 iQ TT`QtBK i2
Qm` T`QTQb2/ H;Q`Bi?KX

kXj :`BTT2`b 7Q` P#D2+i J MBTmH iBQM

_B;B/ :`BTT2`b bmi`v@bi M/ `/ `B;B/ ;`BTT2`b bm+?2Q#QiB[
6` MF > M/ (M/ i?2 C *P ;`BTT2`b `2(T ` HH2H K2+? MBbKb iQ TBM
Q#D2+i #2ir22M irQ Q` KQ`2 7BM;2`bX h?2b2 ;`BTT2`b `2 + T #H
7Q` BMbi M+2- i?2 6` MF > M/ mb2/ BM Qm` 2tT2`BK2Mib + M T
mT i7Q L +`Qbb bi`8Q K2 KQ 7"mi r?BH2 i?2b2 ;`BTT2`b `2 bmBi #H2
?2 pv Q#D2+ib- i?2v + MMQi 2 bBHv ;` bT bK HH- MmK2`Qmb- Q`
6B;m`2/kX

aQ7i :`BTT2`b 7X ;`BTT2`b b22F iQ //`2bb i?2 b?Q`i+QKBM;b Q7 i?
h?2`2 `2 p `B2iv Q7 bQ7i, T2`Q/b2ib`B2;H2b(Mi `2 TT`Q +?2b i? i
/?2bBXp2b? Bb BM+Hm/2b ;2+FQ@ BMbT`2/- 2H2b+B`pQ2bi(iB+ /?2bB
(Re3)- /`v /?2bBM)-2bM/ i?2`K H /?2bXBp+2Q(b 2 +? Q7 i?2b2 TT`Q +
/?2bBp2 Bb +QK#BM2/ rBi? bQ7i K i2`B Hb iQ +`2 i2 Qp2` HH +Q

r v- i?2 `Q#Qi M2p2` mb2b `B;B/ +QKTQM2Mib iQ BMi2` +i rBi? i `
/2bB;Mb BKT`Qp2 i?2 `Q#Qiöb #BHBiv iQ ;`BT bK HH M/ B``2;m
bi`m+im`2 7mM/ K2Mi HHv HBKBib i?2 ;`BTT2`öb X T +Biv iQ 2t2`i

_B;B/@aQ7i :`BT `?2bvX TQi?2bBb Bb i? i i?2 +QK#BM iBQM Q7 `B;B
QT2Mb i?2 /QQ` iQ /Bp2`b2 Q#D2+i K MBTmH iBQMX B_;2+/2Mi/rQ`Fb
bQ7`iBTT2`b #v BMi2;` iBM; #Qi? 2H2K2Mib BMkdQ- i?2 ?2 Q#Qiöb 7BM
d3dNX q2 MQi2 i? i i?2b2 2tBbiBM; `B;B/ MQ bMQ7ip;2 BT 2/`?/2bBp2Mb
6Q` 2t KTH22iS H(dX BMi2`bT2`b2 `B;B/ #HQ+Fb i?`Qm;?Qmi bQ7i K
2i H(dX8 p `v 7BM;2`öb biB77M2bb #v HQ+FBM; Bib2`iB;HdX# +F#QM
bBKBH `Hv +QMM2+i `B;B/ HBMFb rBi? bQ7i DQBMib iQ K F2 7BM
2i H(dX3 M/ > 2i H(dXR mb2 i2M/QM@/`Bp2M K2+? MBbK iQ +QMi`Q
i?2 7BM;2`b- r2iBH(dX9qBM i2;` i2 DQBMi2/ 2M/QbF2H2iQM bi`m+im`
7BM;2`b iQ T`QpB/2 ?B;?2` ;`BTTBM; 7Q`+2X Pp2` HH- i?2b2 bi
;` bTb i? i `2 #Qi? `B;B/ M/ bQ7i, i?2 Q#D2+i Bb ?2H/ #v 7BM;2`b
M/ +QKTHB Mi +QKTQM2MibX "v +QMi` bi- _AaP ;`BTT2`b r2 H+v M T2
`B;B/ mbBM; BM/mbi`v@bi M/ `/T`mB;2H+vUBQ7B2Mb V/?2bBp2b TH +2/
iBTb Q7 i?2 `B;B/ K2+?X MBbK (B;B/ ?B;?@H2p2H M/ bQ7i HQr@H
TQbbB#H2 #v i?2 mb2 Q7 MQp2H +H bb Q7 brBi+? #H2 /?2bBp2b

arBi+? #H2 /?2bBp2b X i2 _AaP ;`BTT2`b r2 H2p2` ;2 `2+2Mi /p M
K i2`B 3HdX (h?2b2 /?2bBp2b `2 brBi+? #H2, #v +iBp iBM; i`B;;2`
T`2bbm`2 iQ bQ7i K2K#` M2V r2 +QMi`QH i?2 H2p2H Q7 /?2bBQM
Q#D2+ibX *m``2Mi `2b2 `+? ? b 7Q+mb2/ QM +? ` +i2`BxBM; i?2 K
bBQM 7Q`+2b- b r2HH b ?Qr [mB+FHv i?2 K i2`B 3k3j-M9bX rBi+? #
>Qr2p2`- T`2pBQmb rQ`F ? b MQi TTHB2/ i?2b2 bQ7i /?2bBp2b iQ

*? Ti2` j

G2 `MBM; G i2Mi +iBQMb rBi?Q

>mK M .2KQMbi` iBQMb

q2 7B`bi +QMbB/2` i?2 + b2 r?2`2 `Q#Qib M22/ iQ K T HQr@/BK
/BK2MbBQM H #2? pBQ`b i? i ++QKTHBb? bQK2 i bF BM i?2 2M
T `iB+mH `Hv `2H2p Mi BM i?2 +QMi2ti Q7 r?22H+? B` KQmMi2/ `
mbBM; k@.Q6 DQvbiB+FX :Bp2M M 2MpB`QMK2Mi- i?2b2 bbBb
iQMQKQmbHv `2+Q;MBx2 i?2 TQbbB#H2 /Bp2`b2 #2? pBQ`b BM i?2
/2KQMbi` iBQMb Q` 722/# +F- M/ K T i?2K iQ H i2Mi +iBQMb i? i
HQr@/BK2MbBQM H DQvbiB+FX am+? bvbi2K + M `2/m+2 i?2 /2T
2ti2`M H + `2;Bp2`b- r?BH2 2Mbm`BM; i? i i?2v + M ++QKTHBb? i

jXR AMi`Q/m+iBQM

bbBbiBp2`Q#Qi `K KQmMi2/ QM r?22H+? B`b + M ?2HT iQ BKT`Qp
HBQM /mHib BM K2`B+ r?Q bm772` N)XQ K T ?;BbM2+ `2K/Q b2 #B+ Q iB2`
`Q#Qi `K mbBM; k@.DQvbiB+F iQ T2`7Q`K bQK2 i bF bQ 7 / BHv
(Ry)X uQm rQmH/ ? p2 bQK2 i bF BM KBM/ i? i vQm jXR HiQQT2`7Q`K
i i?2 2MpB`QMK2Mi- i?2`2 `2 irQ i bFb i? i vQm + M T2`7Q`K- BX
`2 +?BM; 7Q` i?2 +mTX hQ T2`7Q`K 2Bi?2` Q7 i?2b2 i bFb- vQm rQ

6B;m`2 jXR, >mK M i2H2QT2` iBM; M bbBbiBp2 `Q#Qi `KX q2
`Q#Qib + M H2 `M mb27mH i2H2QT2` iBQM K TTBM;b rBi?Qmi ?m
7Q` ?B;?@2Mi`QTv M/ Q#D2+i@`2H i2/ #2? pBQ`b- M/ i?2M 2K#
BMiQ mb2`@+QMi`QHH2/ H i2Mi bT +2X >2`2 i?2 `Q#Qi miQMQ
DQvbiB+F BMTmib iQ /2ti2`Qmb- +QQ`/BM i2/ KQiBQMb i? i`2 +?

i?2 ?B;?@/BK2MbBQM H `Q#Qi rBi? i?2 k@. DQvbiB+F- K FBM; i?

i?Bb bBim iBQM- B7 i?2 bbBbiBp2 `Q#Qi `K + M `2+Q;MBx2 i?2 i

?2HT vQm iQ T2`7Q`K i?2 i bF #v +QQ`/BM iBM; Bib KQiBQM rBi?

DQvbiB+FX 6Q` BMbi M+2- i?2 `Q#Qi + M /B`2+iHv K M M BMTmi

#2? pBQ`b i? i + M H2 / iQ bm++2bb7mH i bF +QKTH2iBQMX 6Q`

DQvbiB+F ;mB/2b i?2 `Q#Qi `K iQ `2 +? 7Q` i?2 +mT- r?BH2 T`2b

;mB/2 i?2 `Q#Qi iQ `2 +? 7Q` M/ QT2M Q` +HQb2 i?2 /` r2`X

_2+2Mi rQ`Fb ? p2 7Q+mb2/ QM T`QpB/BM; i?2 `Q#Qi `Kb rBi? i

K TTBM;b i? i K T HQr /BK2MbBQM H `Q#Qi +iBQMb iQ ?B;? /BK2M

+iBQMb iQ kX h?2b2 T`BQ` rQ`Fb `2[mB`2 + `2;Bp2` UMQM@/Bb #

`Q#Qi rBi? /2KQMbi` iBQMb Q7 HH TQbbB#H2 i bFb BM i?2 2MpB

`2 i?2M mb2/ #v i?2 `Q#Qi iQ H2 `M H i2Mi 2K#2//BM;b i? i rQmH

2 bBHv T2`7Q`K i?2 i bFb BM i?2 2MpB`QMK2MiX

h?Bb TT`Q +? `2HB2b QM i?2 bbmKTiBQM i? i + `2;Bp2`Q` MQM #H2 iQ /2KQMbi` i2 i?2 i bFb BM i?2 2MpB`QMK2Mi iQ i?2 `Q#QiX > #2?BM/ mbBM; bbBbiBp2 `Q#Qi `Kb Bb iQ `2/m+2 i?2 /2T2M/2M+2 Qi?2` BM/BpB/m HbX q2 r Mi iQ 2M #H2 i?2 `Q#Qib iQ H2 `M H i2M ?mK M BMTmib Q` bmT2`pBbBQMX Pm` +Q`2 ?vTQi?2bBb Bb i? i 2 i?2 2t +i i bFb iQ #2 T2`7Q`K2/-Bi + M H2 `M H i2Mi +iBQMb i? i K #v H2p2` ;BM; i?2 7 +i i? i,

bbBbiBp2 `Kb `2 T`BK `BHv mb2/ iQ BMi2` +i rBi? Q#D2+ib BM H2 /BM; iQ +? M;2 BM i?2B` bi i2X

"mBH/BM; QM i?Bb ?vTQi?2bBb-r2 r Mi iQ 2M #H2 i?2 `Q#Qib iQ H + M +? M;2 i?2 bi i2 Q7 i?2 2MpB`QMK2Mi BXM/Bp2`b2/ #2? pBQ`b i? i H2 / i?2 `Q#Qi iQ `2 +? 7Q` i?2 +mT-Tmb? i?2 +mT i?2 /` r2`-2i+X h?2b2 mMbmT2`pBb2/ #2? pBQ`b + M i?2M #2 2t2+ ;2M2` i2 /Bp2`b2 /2KQMbi` iBQMb iQ H2 `M H i2Mi 2K#2//BM;bX

AM i?Bb +? Ti2`-r2 T`QTQb2 M TT`Q +? iQ H2 `M H i2Mi +iBQM i? i 2M #H2b bbBbiBp2`Q#Qi `Kb iQ H2 `M miQMQKQmb TQHB+ K2Mi BM/Bp2`b2 r vbX h?Bb TT`Q +? rBHH miQK iB+ HHv H2 / i? i2H2QT2` iBQM K TTBM;b #v K MBTmH iBM; i?2 2MpB`QMK2Mi i?2 i bF@ ;MQbiB+ K MM2`X

jXk S`Q#H2K 6Q`KmH iBQM

q2 +QMbB/2` b+2M `BQb r?2`2 ?mK M Bb i2H2QT2` iBM; i?2B` bb
2MpB`QMK2MibX h?2 ?mK M +QMi`QHb i?2 `Q#Qi rBi? DQvbiB+F
BMi2`T`2i i?2 ?mK Möb HQr@/BK2MbBQM H +QKK M/b iQ T2`7Q`K
i?2 ?mK MX

1MpB`QMK2Mib i?2 r?22H+? B`@KQmMi2/ `Q#Qi `K KQp2b `QmM/
rBHH BM2pBi #Hv 2M+QmMi2` p `B2iv Q7 2MpB`QMK2Mib U2X;X-
/2bFVX q2 7Q`KmH i2 2 +? 2MpB`QMK2Mi b M mM/Bb+QmMi2/ J `
`2r `/ bM, = hS;A;TiX >2s`2S Bb i?2 bvbi2K2bA i2R$^{n}$ Bb i?2 `Q#Qi +iBQM
M/T(s;a) + Tim`2b i?2 /vM KB+baXBb?2B;+?@QBMK2MbBQM H, BM Qm`
a 2 A R^{n} Bb i?2 DQBMi p2HQ@+Bi6 `Q7#Q?i2 `KX "mi iB?2 b?B2,?2`
/BK2MbBQM, Bi BM+`QmMi2ö #Q2ib #UQ2iX;X-2Bib DQBMi TQ?b2BQ7MQV#DM2/+ii?b2
BM i?2 2MpBÙQ2M;KX2-MpiBbm HQ#b2`p iBQMb 7`QK M _:"+ K2` VX qB
r2 bBKTHB7v i?Bb #v bbmKBM; i? ir2 ? p2/B`2+i ++2bb iQ i?2 Q#
i?2B` TQbBiBQM MX [R] 2BM2+M2i- iB Q`Bi2 is?2(s$_{R}$;s$_{O}$) - b?2s$_{R}$2 R^{n} Bb
i?2 `Q#Qiöb DQBMBb b?2BTBQ?@Qi? iQ?2D 2s$_{O}$ i=(o$_{1}$;o$_{2}$;:::;o$_{K}$)2 R^{m} Bb
p2+iQ` i? i BM+Hm/2b i?2 TQb2 Q7 2 +? Q#D2+i BM i?2 2MpB`QM

_2+ HH i? i i?2 ?mK M M/ `Q#QirBHH BMi2` +i BM b2p2` H /B772
K HHvp(M)2/2MQi2 /Bbi`B#miBQM Qp2` 2MpB`QMK2Mib-bQ i? i bi
i?2 ?Qmb2 i?2v b KTH2M2MpB`QMK2Mi2M?/Q2b MQi BM+Hm/2 `2
r `/ 7mM+#iB+Qmb2 r2 /Q MQi FMQr r? i i bF UQ`i bFbV i?2 ?mK M rB
rBi?BM 2 +? 2MpB`QMK2MiXT2`7Q`K2/ BM i?2 2MpB`QMK2MiX

[R] h?Bb bBKTHB7B+ iBQM K i+?2b `2+2Mi rQ`F QM H i2Mi +iBQMb r?2`2 i?2
/2i2+iBQM KQ/2H iQ 2ti` +i Q#X2+i HQ+ iBQMb (

6B;m`2 jXk, Pm` T`QTQb2/ TT`Q +? 7Q` H2 `MBM; bbBbiBp2 i2H
?mK M bmT2`pBbBQMX UG27iV qBi?BM bBKmH i2/2MpB`QMK2Mi
#2? pBQ`bi? iK tBKBx2 Q#D2+i2Mi`QTv 2X;X-i?2 `Q#QiH2 `Mb
KQmMibX UJB//H2V q2 i?2M b KTH2i` D2+iQ`B2b 7`QKi?2i` BM2
+iBQM T B`b +`Qbbi?2b2i` D2+iQ`B2b 7`QKi?2i` BM2
Q#D2+i `2H i2/ KQiBQMb BMiQ H i2Mi +iBQMb #v H2p2` ;BM; b
U_B;?iV q2 TTHv i?2 H2 `M2/ /2+Q/2` rBi? ?mK M@BM@i?2@H
?mK Möb DQvbiB+F BMTmib iQ +QQ`/BM i2/- Q#D2+i@`2H i2/ +i
2t +iHv ?Qr 7 `i?2 `Q#QiQT2Mb i?2 /` r2`X

h2H2QT2` i_B2QmM`XMBM; iQ Qm` 2t KTH2 2MpBj`XRiV?2`MQi#7Q`/KQ2B;mQ2
FMQr r?2i?2` i?2 ?mK M r Mib iQ QT2M i?2 /` r2`- TB+F mT i?2 +m
Qi?2` mM2tT2+i2/ i bFX hQ +QMp2v i?2B` BMi2Mi i?2 /Bb #H2/ mb
#v TTHvDBQMv;biB+Fu2BMTmrfX q2 `2+Q;MBx2 i? i i?2`2 `2 K Mv i2H2
/2pB+2b bm+? b bBT@kMQ@ T#m7BMiQ+QHKT(mi28 B#Mm2`?2+2b2(
7Q+mb QM DQvbiB+Fb bBM+2 i?2v `2 i?2 KQbi T`2p H2Mi BMTmi
KQmMi2/ `Q#QiyX kAbK(TQ`i MiHv-i?2 /BK2MbBQM Q7 i?2 mb2`öb DQ
/BK2MbBQM Q7 i?2 `Q#Qdi<ömbVXiB2QMM+b2T r+22MU22/ K TTBM;i? i +QM
?mK MHöbr@/BK2MbBQMB +HF BMTm?@/BK2MbBQM+HBQMbX

G i2Mi +iBQSMbXQ` rQ`F QM b? `2/ miQMQKv bbmK2b T`2@/27
K TTBM;rBi? KmHiBkT-32aXK?Q2MbbB/2`2m@bBQM;DQvbiB+F iQ +QMi`QH
`K, vQm` DQvbiB+F KQp2b i?2 `Q#QiöxbQ@2MM2/b@B27Q+Mi2Q`k@H2-MB;M?
roll t2b BM MQi?2` KQ/2- M/ bQ QMX "vH+2QMM` bTi`-Qr22b+2BFQMQ7mM
i? i K Tb HQr@/BK2MbBQM H mb2` BMTmib BMiQ ?B;?@/BK2MbB

A M b T B `2 / # v `2 + 2 M i `2 b 2 `+ ? [illegible] b

a = (z; s) U j X R V

> 2 `z 2 2 Z R^d B b H Q r @ / B K 2 M b B Q M H H i 2 M i + i B Q M i ? i i ? 2 ? m K M -
i ? 2 b B @ / B K 2 M b B Q M H D Q v b i B i + F X b h B ? M / 2 B Q / 2 M T m i b r 2 H H b i ? 2 b v
s - M / Q m i T m i b ? B ; ? @ / B K 2 M b a B X Q M m H ` Q # D Q 2 i + i B i ? 2 Q M M 2 + i Q / 2 `
i ? i 2 M # H 2 b i ? 2 `Q # Q i i Q T 2 `7 Q `K p `B 2 i v Q 7 m b 2 7 m b M + i B Q M b -
b Q i ? i i ? 2 ? m K M + M b 2 K H 2 b b H v + Q M i `Q H i ? 2 `Q # Q i X "m i Q m `
/ 2 + Q / r 2 B i ? Q m i b m T 2 ? Q B b Q 2 M B / 2 M i B 7 v K 2 M B M ; 7 m H H i 2 M i + i B Q M
? m K M @ T `Q p B / 2 / / 2 K Q M b i ` i B Q M b Q ` T `2 @ / 2 7 B M 2 / i b F b \

j X j G 2 `M B M ; l M b m T 2 `p B b 2 / G i 2 M i + i B Q M b

h Q H 2 `M M b b B b i B p 2 i 2 H 2 Q T 2 ` i B Q M K T T B M ; r 2 `2 i m `M i Q Q m
`Q # Q i b i Q H i 2 ` i ? 2 b i i 2 Q 7 Q # D 2 + i b `Q m M / i ? 2 K X S m i M Q i ? 2 `
B M T m i b b ? Q m H / + m b 2 i ? 2 `Q # Q i i Q T 2 `7 Q `K + i B Q M b H B F 2 `2 + ? B
B M ; - Q ` `Q M 2 B M v Q X D P 7 + i b Q m `b 2 - M Q i H H Q 7 i ? 2 b 2 + i B Q M b T T H v
M Q T 2 M B M ; K Q i B Q M K B ; ? i + ? M ; 2 i ? 2 b i i 2 Q 7 / ` r 2 `- # m i r B H H
q 2 i ? 2 `2 7 Q `2 T `Q T Q b 2 M T T `Q + ? r ? 2 `2 i ? 2 `Q # Q i b i Q M K T M 2 b 2 M p B
m i Q M Q K Q m b / H B v p 2 H 2 b 2 M + i B Q M b 7 Q ` i ? 2 b T 2 + B 7 B + Q # D 2 + i b B M i ? Q
i B Q M j X R q 2 i ? 2 M 2 K # 2 / i ? 2 b 2 / B p 2 `b 2 # 2 ? p B Q `b B M i Q H Q r @ / B
b T + 2 U b 2 2 j X j X R P M 2 ` H H - Q m ` m M b m T 2 `p B b 2 / T T j X j X R H 2 ? Q m i H B M
H i 2 M i + i B Q M b i ? i H i 2 ` M 2 `# v Q # D 2 + i b U 2 X ; X - T `2 b b B M ; `B ; ? i i
2 M # H B M ; i ? 2 ? m K M i Q i 2 H 2 Q T 2 ` i 2 i ? 2 `Q # Q i + `Q b b p `B 2 i v Q 7
Q m i 2 p 2 ` `2 [m B `B M ; T `2 @ b T 2 + B 7 B 2 / i b F b Q ` ? m K M / 2 K Q M b i ` i B

a2+iBjQXjXRM/jXjXQk++m` rBi?Qmi ?mK M@BM@i?2@HQQT, Qm` 7BM
/2+Q/2` BM 1[mXVRBQ?MB+U? Bb i?2M H2p2` ;2/ #v i?2 ?mK M iQ +QMi`

jXjXR G2 `MBM; .Bp2`b2 "2? pBQ`b

AMi`BMbB+ _2Bp2XM QM2 Q` KQ`2 2MMpB`QMK2MiX HH H2p2` ;2 mMb
T2`pBb2/ T`2@i` BMBM; iQ B/2MiB7v /BMb2/`Qb2b#2?2QipBMQ+bX m/2+`2rH
7mM+iBQM bBM+2 r2 /Q MQi FMQr r? i i bFb i?2 ?mK M ? b BM KBM
MBMi`B`2bB+ 7mM+iBQM i? i 2M+Qm` ;2b i?2 `Q#QiiQ /Q irQ i?BM
Q#D2+i bi i2 2MMiUQ#TvKBMB/KBBxi2M?2 iQXQ#D2+HisO i?QMi BMb i?2
bi i2 Q7 2 +? Q#D2+i BM i?2 2MpB`QMK2MiX q2 r Mi iQ Hi2` i?Q
(9k9j-9998) - BX2X- r2 r Mi iQ K tBKBx2 p(sO) 2M"imQ TQ +Q M2` +i rBi?
Q#D2+ib i?2 `Q#QiKmbi 7B`bi `2 +? i?2K, ?2M+2- r2 b? T2 i?2 BMi
i?2 /Bbi M+2 #2ir22M i?2 `Q#Qiöb 2M/@27 7o2+sOQX` hM7Bb?2 +HQiQ2bi
i?2 `2r `/ 7mM+iBQM,

$$r(s) = H(s_O) \quad \underset{o2 s_O}{K} B N(s_R;o) \qquad \text{UjXkV}$$

r?2`H2 Bb i?2 a? MMQM 2M(s_R;o) Bb i?2 /Bbi M+2 #2ir22M i?2 `Q#Qiöb 2
M/ Q#D2+aiBM+2 +QKTmiBM; bi i2 2Mi`QTv BbivTB+ HHv BMi` +i #
i?2 T `iB+H2@# b2/ 2biBK i2 7`Q(s_O), GBm M/ ##22H (

$$r(s) \quad H(s_O \quad s_O^k k \quad \underset{o2 s_O}{K} B N(s_R;o) \qquad \text{UjXjV}$$

>2`s_O Bb i?2 +m``2Mi bi i2 Q7 Q#D2+ib s_O^k MBi?2 2@M?2 pB`2QMK2MiBM;/?#Q
b i?2 `Q#Qi BMi2` +ib rBi? i?2 2MpB`QMK2Mi Bi K BMi BMb `2T
bi i2b, iQ +Q s_O^k K T?2i2Q#Qi bBKTHv b2 `+?2b i?`Qm;? i?Bb #m772`X
i2`K BM 1[mjXBVQ`M2rU`/b i?2 `Q#Qi 7Q` KQpBM; Q s_O D2+iBb BM2Qv bi

/B 7 7 2 `2 Mi i? M i?2 Q # D 2 + i bi i2 b i?2 `Q # Qi ? b `2 + 2 MiHv Q # b2 `p2

_ 2 B M 7 Q `+ 2 K 2 Mi G 2 M M2 B M 1 [X m i B X Q Mi ?2 `Q # Qi B b + Q M bi MiHv b 2 2 F

M/ mMB[m2 Q # D 2 + i bi i2 b X _ 2 im `MBM; iQ Qm` 2 t + K H T Q H b 2 2 B K ; B M

/` r2 `/m`BM; i?2 T`2 pB Q mb B Mi2` + iB Q M /m`BM; i?2 M2 ti B Mi2` +

Bib `2 r `/Q # Tv 2 Mi B M 1 ;/` r2 `X q2 + + Q `/BM; Hv mb2 `2 B M 7 Q `+ 2 K 2 Mi H

miQ M Q K Q mb `Q # Qi # 2 ? pB Q `b i? i K tB K B x 2 i? 2 $\sum_{t=0}^{1} B b + r(s_t)$ X Mi2/ b m K

a T 2 + B 7 B + H H a v Q 7 2 + T i Q H v @ * a `B V B + M Q 7 7 @ T Q H B + v `2 B M 7 Q `+ 2 K 2 Mi H

7 Q ` + Q M i B M m Q mb bi i2 M d X + q B ? Q M m T B + M 2 b Q m ` `2 r `/ 7 j X Q V K 1 [m i B

a * i` B M b i?2 `Q # Q i i Q i F 2 mi a M ? Q i K K Q m B K B + x B Q ? M 2 b Q # D 2 + i bi i2 2 M

+ `Q b b i?2 `2 T H v # m 7 7 2 `X h ?2 Q m i T m i Q 7 i?2 7 B `b i H 2 `i Q 7 2 /Q m `

`Q # Q i T Q a J B + iv ? i ; 2 M 2 ` i2 b /B p 2 `b 2 - Q # D 2 + i @ `2 H i2 / K Q i B Q M b X

j X j X k 1 K # 2 / / B M ; . B p 2 `b 2 " 2 ? p B Q ` i Q G i 2 M i + i B Q M b

. i b 2 i X A M i?2 b 2 + Q M / T `i Q 7 Q m ` T T `Q + ? r 2 H 2 p 2 ` ; 2 i?2 H 2 `M

i B Q M j X j X Q i ` B M H i 2 M i + i B Q M b X q 2 $(a_i; s_i)$ - r i B ? i 2 ? `2 Q m H B + v Q 7 m M b m T 2 `

T `2 @ i ` B M B M ; + `Q b b Q M 2 Q M K Q M 2 X M p 2 B `2 Q M 2 K i 2 M H b v `Q H H Q m i i ? B b

i Q ; 2 M 2 ` i 2 `Q # Q i i `= $(s_0; a_0)$ $(s_1; a_1)$ : : : $(s_T; a_T)$ X " 2 + m b 2 i ? 2 `Q # Q i ? b # 2

i ` B M 2 / i Q K t B K B x 2 Q # D 2 + i bi i2 2 M i `Q T v - 2 + ? Q 7 i ? 2 b 2 i ` D 2 + i Q

2 7 7 2 + i Q M Q # D 2 + i b B M i ? 2 2 M p B `Q M K 2 M i , 2 X ; X - Q M 2 i ` D 2 + i Q `v

T B + F b B i m T - M / i ? B `/ Q T 2 M b i ? 2 / ` r 2 `X 6 B M H H v - r 2 ; ; `2 ; i 2 i ?

2 + ? i ` D 2 + i Q `v i Q 7 Q `K + m D K = m f $(s_0; a_0)$ $(s_1; a_1)$ ; 1 2 g i X P 7 + Q m `b 2 - T `2 p B Q

`2 b 2 `+ ? Q M H i 2 M i + i B Q M b H b Q m i B H B x 2 b / i b 2 i D # B m i ?2 F 2

miQ M Q K Q m b H v ; 2 M 2 ` i2 / # v i ?2 `Q # Q i - M / / Q 2 b M Q i `2 [m B `2 M v

1 K # 2 / / B M L ; X r i ? i r 2 ? p 2 / i b 2 i Q 7 / B p 2 `b 2 - Q # D 2 + i @ `2 H i2 / + i B

i?2b2 ?B;?@/BK2MbBQM H +iBQMb BMiQ HQr@/BK2MbBQM H H

rQ`F QM H i2Mi R-iBMQ/MHb2(p2` ;2 +QM/BiBQ M3X hm2Q+Q/2Q/2` (

S A!Z 2K#2/b i?2 /2KQMbi` i2/ #2? pBQ` BMiQ i?2 22HQi/2Mi bT +

:Z S!A 7`QK 1[m jXQ mb2b i?2 ?mK Möb DQvbiB+F BMTmib UBX

iQ `2+QMbi`m+i`Q#Qi +iBQMbX q2 bBKmHi M2QmbHv i` BM i?2 2

i?2 +iBQM `2+QMbi`m+iBQM HQbb +`Qbb i?2 / i b2i,

$$L = \sum_{(s;a)2D} a \quad (s;a);s^{2} \qquad \text{UjX9V}$$

6BM HHv- r2 ;Bp2 i?2 i` BM2/ /2+Q/2` iQ i?2 ?mK M bQ i? i i?2v +

`KX hQ mM/2`bi M/ r?v i?Bb TT`Q +? rQ`Fb- BiBb BKTQ`i MiiQ `2

BhQM/BiBQMb i2 r?B+? BM+Hm/2b #Qi ?s i?2 M/ Q?#2QQ#i 22s bX i2b

>2M+2- i?2 r v i? i i?2 `Q#QiBMi2`T`2ib i?2 ?mK Möb BMTmib /2T2

2X;X- B7 i?2 /` r2` Bb KQp2/ iQ i?2 `B;?i- MQr i?2 `Q#QirBHH `2 +

iQ QT2M i?Bb /` r2`X

jXjXj bbmKTiBQMb

Pm` TT`Q +?iQ bbBbiBp2i2H2QT2` iBQM `2/m+2b i?2 `2HB M+2

i?2`2 Bb MQ 7`22 HmM+? M/ ?2`2 r2 irQi ibQ mKTT?BbQMb #?22 mb

iQ H2 `M H i2Mi +iBQMb rBi?Qmi ?mK M bmT2`pBbBQMX

++2bb iQ UaBKmH i2/V 1MpBB`QMK2Mibx mK2 i? i r2 FMQr bQK2 Q7

pB`QMK2Mib i?2 ?mK M rBHH `BQ2X- rBi? M /` M b kQ(MH)2b

.m`BM; BKTH2K2Mi iBQM r2 7Q`K bBKmH i2/ p2`bBQMb Q7 i?2b2

bmT2`pBb2/ T`2@i` BM jXjXR q2 K aM2K BBQMi2 i?Bb bbmKTiBQM #v

H `;2@b+ H2 BMi2` +iBp2 bBKmH iB3QMXb Q7 ?QK2 2MpB`QMK2Mib

6B;m`2 jXj, aBKmH i2/ ?mK M +QMi`QHHBM; i?2 S M/ `Q#Qi `K
iBQMbX q2 +QKT `2 H i2Mi +iBQMb i` BM2/ QM ?mK M@T`QpB/2
UEBM2bi?V2iBM/ i2H2QT2` i2/ /2KQ2MbiV TQQmb`UmMbmT2`pBb2/ TT
UPm`bX q2 HbQ +Q2MH2QT2i?2 T `iB+BT Mibö /2KQMbi` iBQMb #2+Q
MQBbv M/ BKT2:0:12 +iU1VXPm`bQmiT2`7EQ`K2bi?2MB+MQBbv p2`bBQM
Q?2H2-QTM/ Bb bHB;?iHvhr2H2QT2:0:0VX Pm` K2i?Q/2M #H2bi?2 `Q#
K i+? T`BQ` H i2Mi +iBQM TT`Q +?2b rBi?Qmi`2[mB`BM; Mv ?m

++2bb iQ P#D2+i a2+iQXM/- r2 bbmK2 i? i i?2 `Q#Qi + M K2 bm`2

Q#D2+ib- BX2X- i?2s`QX#Qi BQ#`b2Qp2bQM H i2Mi +iBQMb mb2b T`2

/2i2+iBQM KQy/i2H2Q#(i BM i?2 Q#D2+i bi i2 7RQX P:#D2K+i;2bi2+iBQM

M/ +H bbB7B+ iBQM Bb HbQ bmBi #H2 7Q` Qm` T`QTQb2/ TT`Q

K v 7 BH B7 i?2 `Q#Qiöb pB2r Q7 i?2 Q#D2+ib Bb Q#bi`m+i2/X

jX9 *QKT `BbQM iQ >mK M .2KQMbi` iBQMb

AMi?2 T`2pBQmb b2+iBQMb-r2? p2 7Q`K HBx2/Qm` TT`Q +? 7Q

?mK MbmT2`pBbBQMX Pm`T`QTQb2/ TT`Q +? 7B`biH2 `Mb TQH

mbBM;mMbmT2`pBb2/T`2@i` BMBM; M/i?2M 2K#2/bi?2b2#2? p

+iBQMbX AM i?Bb b2+iBQM- r2 +QM/m+i 2tT2`BK2Mib BM +QMi`Q
T2`7Q`K M+2 Q7 i?2 H i2Mi +iBQMb i` BM2/ mbBM; Qm` mMbmT2
H i2Mi +iBQMb i` BM2/ mbBM; ?mK M T`QpB/2 /2KQMbi` iBQMbX

>mK M .2KQMbi` iBQMbX `mBi2/ d #H2 #Q/B2/ T `iB+BT Mib 7`Q
h2+? +QKKmMBiv U 24 2`3:5`2X ;1 +? T `BiB+BT Mi T`QMb2Bi?/2#Q+?
b r2HHh2bH2Q2TKQMbi` iBQMb iQ i?2 `Q#QiX bQ?2?2KQpM/2i` iBQMb-
i?2 T `iB+BT Mib T?vbB7+ DHHv6;mMBF/2/1KBF S M/ `Q#Qi `K iQ T2`
/B772`2Mi i bFbX h?2b2 `2T`2b2Mi i?2 b2i Q7 /2KQMbi` iBQMb i?
#Q/B2/+ `2;Bm2H2XQiA2 mb2`b +QMi`QHH2/iQ TQbBiBQM Q7 i?2 `Q#
DQvbiB+FX h?2b2 `2T`2b2Mi i?2 b2i Q7 /2KQMbi` iBQMb i? i +
mb2`iQ i2 +? /B772`2Mi i bFb iQ i?2 `Q#QiX

q2 `2+Q;MBx2 i? i ?mK Mb `2 MQi T2`72+i M/ i? i i?2v K F2 KBb
i?2b2 /2KQMbi` iBQMbX hQ bim/v ?Qr i?2 KBbi F2b BM i?2 ?mK M
HQr /BK2MbBQM H H i2Mi +iBQMb H2 `M2/ #v i?2 `Q#QiX r +QMb
aT2+B7B+ HHv- r2 // /B772`2Mi H2p2Hb x2`Q@K2 M = 0:01 bB M MQ
=0:01 M/ =0:1V iQ i?2 /2KQMbi` iBQMb T`QpB/2/ #v i?2 T `iB+BT M

.2+Q/2`bX? /2KQMbi` iBQMb T`QpB/2/ #v i?2 T `iB+BT Mib `2 m
KQ/2Hb UH i2Mi +iBQMbV mbBM; TTjXQX+q2/2mb2Mi2 2M2Mia2 +BBQM
/2KQMbi` iBQMb2M2Q2TKQMbi` iBQMb rBi? M/ rBi?Qmi MQBb2 iQ
/ i b2ib 7Q`i` BMBM; i?2 /2+Q/2`b iQ K T i?2K iQ H i2Mi +iBQMb
/2+Q/2`b i` BM2/ mbBM; i?2b2 / i b2ib Bb i?2M +QKT `2/iQ i? iQ7
mbBFm`Xb q2 ?B;?HB;?i i? ir2 2Mbm`2 i? ii?2 `2bmHib Q7 i?Bb 2tT2`
r `/b Qm` T`QTQbT2/ TT`Q +?- r2 +QHH2+iKQ`2/ i Ubi i2@ +iBQ
Q7 ?mK M /2KQMbi` iBQMb i? M i? i +QHH2+i2/ 7`QK mMbmT2`pB
i?2 / i b2i Q7 /2KQMbi` iBQMbX bTM2pB?/2?2Hm2bMP m`+bQKT`Bb2/ Q7

jDj = 23:5k -jDj = 16:3k MjDj = 14:0k bi i2@ +iBQM T B`b `2bT2+iBp2HvX

aBKmH i2/ *QMi`hQH2Hp2 HXm i2 i?2 #2bi + b2 T2`7Q`K M+2 Q7 2 +?
bBKmH i2/ ?mK M iQ T`QpB/2 +QMi`QH BMTmib iQ s?-2i?2 #QiX :
bBKmH i2/ ?mK M r b T`Q;` KK2/ iQ i F2 QTiBK H H i2Mi +iBQMb
7 DoF 6` MF 1KBF _Q#Qi `K iQr `/b i?2 ;Q H,

$$z = \sum_{z \in Z} \mathrm{Res}_{s} \; T\, s;\ (z;s)\ k^2 \qquad \text{UjX8V}$$

r?2`2 (z;s) Bb i?2 /2+Q/2` 7`QK 1Vm i?iBQMiUmib i?2 ?B;?@/BK2MbBQ
+iBQMb T(s;M)/Bb i?2 bvbi2K /vM KB+bX q2 MQi2 i? i2p2M i?Qm;?
r b mb2/ iQ T`QpB/2 +QMi`QH BMTmib- i?2 +QKT `BbQMb 7Q` i?Bb
`2 7 HoF 6` MF @1KBF `Q#Qi `KX

1MpB`QMK2Mib 2M?2bX MpB`QMK2Mib mb2/ BM i?Bb 2tT2`BjKX2Mqi2 `2 b?Q
/27BM2 i?2 bi i2 bT +2 Q7 i?2 2MpB`QMK2Mi M/ i?2 i bF iQ #2 T2`

Ç SQm`BM2, Q#D2+sib`i2iT2`2b2Mib i?2 TQb2 Q7 i?2 +mT ?2H/ BM i?2
M/ i?2 TQb2 Q7 i?2 #QrH TH +2/ QM i?2 i #H2X AM i?Bb 2MpB
iQ + ``v i?2 +mT #Qp2 i?2 #QrH M/ T2`7Q`K TQm`BM; +iBQM

Ç PT2MBM2, Q#D2+sib`i2iT2`2b2Mib i?2 TQbBiBQM Q7 i?2 /` r2` QM
i?Bb 2MpB`QMK2Mi- i?2 ?mK M M22/biQ `2 +? 7Q` M/ QT2M i?

Ç a+QQTHB?M2, Q#D2+sib`i2iT2`2b2Mib i?2 TQbBiBQM Q7 i?2 HB/ M/ i?
i?2 HB/ Bb QT2MX h?2 ?mK M M22/biQ `2 +? 7Q` i?2 HB/ M/ T
BM Q`/2` iQ QT2M i?2 HB/X

Ç SmB?M2, Q#D2+sib`i2iT2`2b2Mib i?2 TQbBiBQM Q7 i?2 # HH TH
h?2 ?mK M M22/biQ `2 +? 7Q` i?2 # HH M/ Tmb? Bi iQ i?`22 /B

6Q` i?2 i bFb r?2`2 i?2 `Q#Qi QMHv M22/b iQ `2 +?i?2 `Q#Qi QMHv M22/b iQ ?2

TT`Q +? b b 2772+iBp2 b i?Qb2 H2 `M2/ mbBM; ?mK M bmT2`pB

* M r2 BKT`Qp2 i?2 mMbmT2`pBb2/ H i2Mi +iBQMb #v BM+Q`TQ`

q2 `2+Q;MBx2 i? i i?2`2 rBHH #2 2MpB`QMK2Mib r?2`2 bQK2 ?mK

`2 p BH #H2 T`BQ`BX AMbi2 / B7 /Bb+ `/BM; i?Bb p BH #H2 /

Qm` mMbmT2`pBb2/ H2 `MBM; TT`Q +?

i` BMBM; #m772` r?2M Bi H2 `Mb iQ T2`7Q`K /Bp2`b2 +iBQMb

iQ BM+Q`TQ` i2 i?2 /2KQMbi` iBQMb BMiQ i?2 mMbmT2`pBb2/ i` B

#m772` Q7 i?2 `Q#QirBi? i?2 p BH #H2 ?mK M /2KQMbi` iBQMbX

/Bp2`b2 #2? pBQ`b QM iQT Q7 r? i i?2 ?mK M ? b T`2pBQmbHv /2K

AM Qm` 7QHHQr@mT 2tT2`BK2Mi- r2 i2bi i?2 T2`_2Q +?

`QMK2Mi b b?QrMj

i?`22 +mTb TH +2/ QM i?2 i #H2X h?2 ?B?;@/BK2MbB1Q@M.QH6`Q#Qi

H i2MibT +2 M/ i?2 bBKmH i2/ ?mK M mb2b i?Bb H i2MibT +2 iQ T

`Q#QiX *QMi` `v iQ i?2 T`2pBQmb 2tT2`BK2Mib- BM i?Bb 2tT2`BK

b2HBM2b QmPTm2`b7Q?2M/ H2 `MBM; BM M mMbmT2`pBb2/ 7 b?BQ

2tTHQBib i?2 `2r `/ 7mM+iBQM #v `2 +?BM; 7Q` irQ Q7 i?2 +HQb2

HQ+ H KBMBK X >Qr2p2`- rP?2MbB2?BM7B2irB?mBKxM T`QpB/2/ /2KQM

iBQMb- r?2`2 i?2 ?mK M ;mB/2b i?2 `Q#Qi iQ HH i?`2P?mbT TQbB

Y h2H2 **Q** miT2`7Q`K2/ HH i?2 # b2HBM2bX

jX8 lb2` aim/v

AM i?2 T`2pBQmb b2+iBQM- r2 2p Hm i2/ i?2 T2`7Q`K M+2 Q7 Qm`

`Q#Qir b BMi2` +iBQM rBi? BM/BpB/m H Q#D2+ibX AM i?Bb b2+iB

Qm` TT`Q +? BM KQ`2 `2 HBbiB+ b+2M `BQb r?2`2 i?2 `Q#Qi BMi2

6B;m`2 jX9, 6QHHQr@mT 2tT2`BK2Mi r?2`2 r2 BMBiB HBx2 Qm` T
iBQMb Ub Y h2HV2XQT?2b2 /2KQMbi` iBQMb ?2HT Qm` TT`Q +? pQB
QMHv `2 +?BM;irQ +mTbV- M/ Qm` TT`Q +? BKT`Qp2b i?2 /2KQM
Qi?2` ?B;?@2Mi`QTv #2? pBQ`bX

+QM/m+i M BM@T2`bQM mb2` bim/v r?2`2 i?2 `Q#Qi ? /iQ;2M2` H

BM T`2pBQmbHv mMb22M HQ+ iBQMb M/ bbBbi i?2 mb2`b BM +QK

7Q`i?Bb BM@T2`bQM mb2` bim/v ,ff2 rpXBQ#Hm2 2X +QKfr i+?\pX4"F[

1tT2`BK2Mi H ah?2?2mX b2`b T`QpB/2/ +QM7i@QH6 6M`TmFb@Q1KBF `Q#
`K mbB2M@.Q6 GQ;Bi2+? 6jRy DQvbiB+FX 1 +? mb2` +QKTH2i2/ 7Q

Ç *H2 `BM;i?2 +Hmii2` QM i?2 i #H2

Ç SmHHBM;i?2 #QrH TH +2/ QM i?2 i #H2 iQr `/b i?2K

Ç SB+FBM;mT +QMi BM2` Q7 bQmT

Ç S2`7Q`KBM; M +iBQM 7Q` TQm`BM;i?2 +QMi BM2` Q7 bQmT

Ç .BbTQb2 Q7 i?2 2KTiv bQmT +QMi BM2` BM i?2 #BM TH +2/ QM

h?2 HQ+ iBQMb Q7 i?2 Q#D2+ib bm+? b i?2 BMBiB H TQbBiBQM Q

6B;m`2 jX8, h bF M/ `2bmHib 7`QK Qm` mb2` bim/vX S `iB+BT Mi
iQ `2KQp2 +Hmii2` UQ#D2+ib R M/ kV- TmHH i?2 #QrH +HQb2` iQ
+QMi BM2` U9V M/ TQm` Bi BMiQ i?2 #QrH- M/ 7BM HHv /`QT i
q2 +QKT `2 Qm` mMbmT2`pBb2/ TT`Q +? Ur?2`2 T `iB+BT Mib BM
/B`2+i 2M/@2772+iQ` +QMi`QH Ur?2`2 T `iB+BT Mib + M mb2 irQ
irQ KQ/2bVX S `iB+BT Mib +QKTH2i2/ i?2 i bF KQ`2 [mB+FHv rBi
bm#D2+iBp2 `2bTQMb2b r/2`2 M QrB2b 5X M+/2`2 M Qp2b 7X

+Hmii2` Q#D2+ib r2`2 +? M;2/ i i?2 bi `i Q7 2 +? BMi2` +iBQMX h

7Bt2/ M//B/MQi +? M;2 +`Qbb BMi2` +iBQMbX

AM/2T2M/2Mi o `B #+Q2kX `2 i?2 T2`7Q`K M+2 Q7 Qm` T`QTQb2/ T

H i2Mi +iBQMb rBi?Qmi ?mK`Mb Qmi?2i pQ7 bMQ M/mbi`1vM@ M/ `/

1772+iQ`H2QT2` iBQM # b2HBM2 M/X @ 1q7?2M+?2bTMi;B+BT Mib mb2/

DQvbiB+F iQ T`QpB/2 +QMi`QH BMTmib i? i/B`2+iHv +QMi`QH i?2

`KX h?2 DQvbiB+F r bK TT2/rBi?irQ KQ/2b iQ +QMi`QH i?2 `Q#Qi

HBM2 ` p2HQ+BiB2b Q7 i?2 2M/@2772+iQ`- r?BH2 i?2 Qi?2` KQ/2

h?2 T `iB+BT Mib mb2/ #miiQM QM i?2 DQvbiB+F iQ brBi+? #2ir2

Qi?2` ? M/- mbBM; Qm`b- i?2 mb2`bö DQvbiB+F BMTmib r2`2 K TT

p2HQ+BiB2bX1 MB@E7?2iQ`mb2`b +QmH/ brBi+? #2ir22M /B772`2M

iQ T2`7Q`K /B772`2Mi i bFb #v T`2bbBM; #miiQM QMPim?2bDQvbiB

r b i` BM2/ +QKTH2i2Hv Q77HBM2 mbBM; bBKmH i2/ p2`bBQM Q

Mv ?mK M T`QpB/2//2KQMbi` iBQMbX

.2T2M/2Mi o `B #q2 K2X bm`2 i?2 T2`7Q`K M+2 Q7 i?2 TT`Q +?2b

K2i`B+bX q2 K2 bQmi`2HiP2K2M #v 2 +? T `iB+BT MiiQ +QKTH2i2 i?2

AM //BiBQM iQ i?2 iQi H iBK2- r2 HbQ K2 bm`2 i?2 iBK2 7Q` r?B+

rBi? i?2 DQvbiB+F iQ Hv- BBK2 2X i?2 iBK2 i? i i?2 mb2`b bT2Mi iQ T

BMTmib iQ i?2 `Q#QiX q2 HbQ K2 bm`2 i?2 bKQQi?M2bb Q7 i?2

i2`Kb Q7 +QBMQbb q2M2v Q`/ i?2 BMTmi T`QpB/2/ #v i?2 mb2`b i 2 +

+QKTmi2 i?2 HB;MK2Mi #2ir22M +QMb2+miBp2 +iBQMb

$$\text{Consistency} = \frac{u^t \ ^1 \ u^t}{ku^t \ ^1kku^tk}$$

UjXeV

HQr2` p HmQ2 7Q`b bm;2/ i? i i?2 mb2` +? M;2/ i?2 /B`2+iBQM

7`2[m2MiHv r?2M +QMi`QHHBM; i?2 `Q#Qi `K mbBM; DQvbiB+F

i i?2 2M/ Q7 2 +? i2biBM; +QM/BiBQM- r2 b7F@i?2 bmb2 GbiFQ2 `iQ+TH

bm`p2vX AM i?Bb bm`p2v- i?2 mb2`b BM/B+ i2/ i?2B` T`27 2`2M+2b

?2HTr7bmH? 2 `Q#Qi2 ?Q r b iQ +QMi`QH i?2 `Q#Qi- r?2i?2` Q` MQi i

iQmM/2`bi?2/mb2`öb BMi2Mi 7Q` `2 +?BMi;miB2Bb;B2 HQ-T?Qp B/2 i?2

+QMi`QH BMTmib iQ b?2Q`Q?2Q`iQ#Qröb KQiBQM r b-T`M2/7B7Q?2 mb2`

mb2 i?2 bT2+B7B+ H;Q`Bi?KX

S `iB+BT Mib M/ S`Q1+02 7m`iB2X+BT Mib r2`2 `2+`mBi2/ 7`QK i?2 oB

+QKKmMBiv rBi? M p2 4` 2:9 years Q7 72K H2VX "27Q`2 bi `iBM; i?2 b

T `iB+BT Mi T`QpB/2/ BM7Q`K2/ r`Bii2M +QMb2Mi iQ T `iB+BT i2

7 B`- r2 miBHBx2/ +QmMi2`# H M+2/- rBi?BM@bm#D2+ib /2bB;M

T `iB+BT Mi T2`7Q`K2/ i?2 2MiB`2 P2mT`bMB/K2BMi2 1BM/2@ r B7?X+iQ`

"2ir22M 2 +? i`B H- i?2 TQbBiBQMb Q7 i?2 Q#D2+ib BM i?2 2MpB`

i?2 +? M;2b BM TQbBiBQMb r2`2 +QMbBbi2Mi +`Qbb #Qi? i?2 +QM

bi `i2/ i?2 2tT2`BK2MiBr2 ?H2 i?2 Qi?2` ? H7 1bMi/@i2/7 7BX+iQ`

iQ 2 +? i2biBM; +QM/BiBQM- i?2 T `iB+BT Mib T` +iB+2/ +QMi`QH

BM Q`/2`iQ 7 KBHB `Bx2 i?2Kb2Hp2b rBi? i?2 i2H2QT2`iBQM K T

>vTQi?2bq2bX /i?2 7QHHQrBM; ?vTQi?2b2b,

>R,q?2M mbBm`bi?2 T `iB+BT Mib rBHH +QKTH2i2 i?2 i bF BM b?

b +QKT `2/MiQ@ 1772+ri?Q`H2 T`QpB/BM; KQ`2 +QMbBbi2Mi +iBQMb

>k,h?2 T `iB+BT Mib rBHHmT`Q2 7`2 in?2B#Mb,2HBM2X

_2bmHib?X2 `2bmHib 7Q` Qm` BM@T2`bQM mb2` bi?X/v q`27bm`kiK `Bx

bi `irBi? M HvxBM; i?2 Q#D2+iBp2 `2bmHib 7`QK i?Bb bim/vX q2 T

i?2 2772+i Q7 i?2 i2biBM; +QM/BiBQM QM 2 +? K2i`B+X q2 Q#b2`p

i bFb BM bB;MB7B+ MiHv b?Q`i2` iB`k2 bm(1;19)=0.12; p<0.05 vX BM;

q2 HbQ Q#b2`p2 i? i P?m2 bim2 bmb;2`b T`QpB/2/ bB;MB7B+ MiHv K

+QMi`QH BMTmib iQ i?2 `Q#Qi BM Q`F(1;19)=14.7; p<0.05 vX 2 i?2 bF U

T`QpB/2b bmTTQ`i 7Q`>QXm` ?vTQi?2bBb

L2ti- r2 KQp2 QM iQ M Hvx2 i?2 bm#D2+iBp2 `2bmHib # b2/ QM i?

mb2`b iQ Qm` bm`p2v [m2biBQMbX q2 7B`bi M Hvx2 i?2 `2HB #B

bm`p2v- M/ i?2M ;`QmT i?2b2 b+ H2b BMiQ +QK#BM2/ b+Q`2X

b+ H2b T`QpB/2/ bi iBbiB+ HHv bB;MB7B+ Mi `2bmHib PXm>Q r2p2`-

iQ #2 K `;BM HHv KQ`2 BMimBiBp2 b +QMK@ 1772 pq<0.07 vX b2 2 BM2

Qi?2` b+ H2b ;2M2P mHHv B7 ?piQ?2`2t+2T2iBQMW/TQ`2 7b2- H2b- ?Qr2p2`-

MQM Q7 i?2b2 /B772`2M+2b r2`2 bi iBbiB+ HHv bB;MB7B+ MiX 6`Q

T`QpB/2 bmTTQ`i 7Q` M/ K F2 Mv +QM+HmbBQMb `2; `/BM; Qm`

jXe amKK `v

ai i2@Q7@i?2@ `i TT`Q +?2b BM H2 `MBM; H i2Mi +iBQMb `2Hv
iBQMb 7Q` i?2 /B772`2Mii bFb BM i?2 2MpB`QMK2Mi r?B+? `2 i?2M
M miQ2M+Q/2`X AM i?Bb +? Ti2`- r2 BMi`Q/m+2/ 7` K2rQ`F i? i2
iQ H2 `M i2H2QT2` iBQM K TTBM;b i? i K T HQr@/BK2MbBQM H +
mb2`b iQ ?B;?@/BK2MbBQM H `Q#Qi #2? pBQ`b rBi?Qmi ?mK M /2
bi2T TT`Q +? i?2 `Q#Qi 7B`bi H2p2` ;2b mMbmT2`pBb2/ T`2@i`
Q#D2+i@Q`B2Mi2/ #2? pBQ`b- M/ i?2M 2K#2/b i?Qb2 #2? pBQ`b
bT +2 7Q` ?mK M +QMi`QHX q2 2tT2`BK2Mi HHv 7QmM/ i? i i?2 `2b
i?2 i2H2QT2` iBQM K TTBM;b H2 `M2/ 7`QK ?mK M /2KQMbi` iBQ
b?Qr i? i T2QTH2 + M 277B+B2MiHv H2p2` ;2 i?Bb mMbmT2`pBb2/
b2iiBM;b rBi? KmHiBTH2 Q#D2+ibX

jXeXR GBKBi iBQMb

.m`BM; Qm` mb2` bim/v- r2 Q#b2`p2/ i? i mbBM; Qm` TT`Q +? i?2
bQK2 +iBQMb i? i r2`2 mM/2bB` #H2 iQ i?2 mb2`bX 6Q` 2t KTH2- T
q?BH2 i?Bb #2? pBQ` K i+?2b Qm` BMi`BMbB+ Q#D2+iBp2 Q7 K t
KBbb2b Qmi QM i?2 BMi2`M H T`BQ`b i? i i?2 ?mK Mb K v ? p2X PM
Bb 2M+Q/BM; i?2 ?mK M 77Q`/ M+2b BMiQ i?2 H i2Mi 2K#2//BM;b
H2 `M iQ T2`7Q`K mM/2bB` #H2 +iBQMbX

*? Ti2` 9

q vTQBMi " b2/ _2BM7Q`+2K2M G2 `MBM; 7Q` _Q#Qi J MBTmH h bFb

AMi?2 T`2pBQmb-r2 BMi`Q/m+2/ 7` K2rQ`F iQ H2 `M H i2Mi 2K#2
+FX AMi?Bb 7` K2rQ`F-r2 H2p2` ;2/ KQ/2H@7`22 `2BM7Q`+2K2
iQ H2 `M /Bp2`b2 #2? pBQ`bX >Qr2p2`-i?2 bi i2@Q7@i?2@ `i `2B
7Q+mb QM +QKTmiBM; i?2 `Q#Qi +iBQMb i 2 +? bi i2 BM i?2 2Mp
i` BMBM; iBK2 iQ H2 `M i bFb BM ;Bp2M 2MpB`QMK2MiX AM i?B
`2BM7Q`+2K2Mi H2 `MBM; H;Q`Bi?K r?B+?-BMbi2 / Q7 H2 `MBM
2MpB`QMK2Mi- H2 `Mb ?B;? H2p2H +iBQMb BM i?2 7Q`K Q7 r vT
i?2 `Q#Qib iQ +?B2p2 ?B;?2` `2r `/b M/ 7 bi2` +QMp2`;2M+2 b +
`2BM7Q`+2K2Mi H2 `MBM; H;Q`Bi?KbX

9XR AMi`Q/m+iBQM

_Q#Qib Q7i2M H2 `M #2? pBQ`b i? i QTiBKBx2 ;Bp2M `2r `/ 7mM
bT2+B7B+i bFX 6Q` 2t 9XTH?2-`BM4 Q Bö;bmQ2# D2+iBp2 BbiQ H2 `M iQ Q
Q`/2` iQ /Q bQ-i?2 `Q#Qi `QHHb Qmi /Bp2`b2 #2? pBQ`b BM i?2 2M

6B;m`2 9XR, Pm`r vTQBMi@# b2/ TT`Q +? 7Q` KQ/2H@7`22 `2BM
iBQMi bFbX h?2 `Q#Qi `K H2 `Mb r?2`2 iQ TH +2 i?2 M2ti r vTQBM
bQHpBM; KmHiB@ `K2/ # M/BiX q2 i?2M 7`22x2 i?2M H/2`2 TM2/iKQ/2
i?2 T`Q+2bb 7Qi+r1vXTQ2BMbi TT`Q +? H2 `Mb i?2 /2bB`2/ i bF +`Qb
Q7 BMBiB H bi i2bc BX2X- i?2 HQ+ iBQM M/ M;H2 Q7 i?2 /` r2`b

7Q` 2 +? #2? pBQ`X h?2 `Q#Qi H2 `Mb iQ i F2 +iBQMb i? i rBHH B
`2+2Bp2/ #v i?2 `Q#Qi /m`BM; 2 +? BMi2` +iBQM- BX 2X +iBQMb r
/` r2`X 1tBbiBM; TT`Q +?2b Q7i2M H2p2` ;2 `2BM7Q`+2K2Mi H2
Q`/2` iQ bQHp2 i?Bb T`Q#H2KX SQHB+B2b K T i?2 bi i2b Q7 i?2 2M
+iBQMbX 6Q` 2t KTH2- r?2M i?2 `Q#Qi Bb M2 ` i?2 ? M/H2 Q7 i?
bHB;?iHv iQ ;` bT Bi- M/ r?2M i?2 `Q#Qi Bb ?QH/BM; i?2 ? M/H2-
iQ QT2M i?2 /` r2`X AM T` +iB+2- i?Bb K2 Mb i? i i i?`Qm;?Qmi i
iQ `2 bQM Qp2` ?mM/`2/b Q7 HQr@H2p2H /2+BbBQMb UBX 2X i?2
/m`BM; i bF 2t2+miBQMVX "mi i ?B;? H2p2H- i?2 i bF Q7 QT2MB
/QrM BMiQ i?`22 bi ;2b, `2 +?BM; 7Q` i?2 ? M/H2- ;` bTBM; i?2 ?

QT2M i?2 /` r2`X hQ i? i 2M/- i?2 `Q#Qi + M bQHp2 i?Bb i bF M/
`2+2Bp2/ #v H2 `MBM; i?2b2 ?B;? H2p2H r vTQBMib M/ BMi2`TQ
HQr@H2p2H +QMi`QHH2`X

AM i?Bb +? Ti2`- r2 7Q`KmH i2 r vTQBMi@# b2/ TT`Q +? 7Q` KQ/
BM;X Pm` rQ`F K BMHv 7Q+mb2b QM `Q#Qi `Kb i? i + M K MBTmH
`2+2Mi `2b2 `+? BM i?Bb /B`-2r2 BQ+MQ(; MBx2 i? i rB/2 ` M;2 Q7 `Q
MBTmH iBQM i bFb + M #2 #`QF2M /QrM BMiQ b2[m2M+2 Q7 ?B;?
r vTQBMibX JQpBM; #2ir22M i?2b2 r vTQBMib Bb r2HH 2tTHQ`2/ `
i?2B` HQr@H2p2H +QMi`QHH2`b iQ N9NBX >2Q7r2 p22M +2 M Q`2 2+iQ QvH(2
i?2 +Q``2+i r vTQBMib i? i 7Q`K i?2b2 i` D2+iQ`B2b- i?2 `Q#Qi Km
ir22M 2tTHQ`BM; i?2 2MpB`QMK2Mi M/ 2tTHQBiBM; `2 b i? i H2 /
7Q`KmH iBM; i?Bb `2BM7Q`+2K2Mi H2 `MBM; T`Q#H2K b J `FQp
TT`Q +? 7Q` `2BM7Q`+2K2Mi H2 `MBM; T`Q#H2K b i? bi(

1 +? r vTQBMi Bb +QMiBMmQmb KmHiB@ `K2/ # M/Bi T`Q#H2K-
b2H2+i2/ #v i?2 `Q#Qi M/ i?2 `2r `/ iQ KQpBM; iQ i? i r vTQBMi

lbBM; i?Bb BMbB;?i- r2 T`QTQb2 M TT`Q +? i? i #mBH/b i` D2+iQ
iQ K tBKBx2 i?2 `Q#Qi `2+2Bp2/ #v i?2 `Q#QiX q2 7Q`KmH i2 i?2
H2 `MBM; T`Q#H2K 7Q` `Q#Qi K MBTmH iBQM i bFb b b2[m2M
M/Bib- r?2`2 2 +? # M/Bi T`Q#H2K +Q``2bTQM/b iQ QM2 r vTQBM
q2 i?2Q`2iB+ HHv /2KQMbi` i2 i? i i?Bb T`QTQb2/ 7Q`KmH iBQM H
+QKT `2/ iQ i?2 2tBiBM; 7` K2rQ`FbX q2 i?2M BMi`Q/m+2 M H;Q
bQHp2b i?2 b2[m2M+2 Q7 KmHiB@ `K2/ # M/Bib i?`Qm;? TQbi2`B
2Mb2K#H2 Q7 KQ/2Hb iQ 2biBK i2 i?2 `2r `/ 7mM+iBQM 7Q` ;Bp2M
i?2 `Q#Qi H2p2` ;2b +QMbi` BM2/ QTiBKBx iBQM iQ b2H2+i r vTQ

2biBK i2 Q7 i?2 `2r `/ 7mM+iBQMX :QBM; # +?bQ`m`H2;tQK BH2K BM
H2 /b i?2 `Q#QiiQ Bi2` iBp2Hv b KTH2 r vTQBMi 7QHHQr2/ #v `Q
i2`KBM i2b i i? i r vTQBMi U2X ;X i`vBM; iQ `2 +? bQK2 TQBMi i
" b2/QM i?2 `2r `/b `2+2Bp2/ 7Q` `QHHBM; Qmi i?Bb i` D2+iQ`v- i?
i?2 r vTQBMi `2r `/ M/ QTiBKBx2b i?2 TH +2K2Mi Q7 i?2 +m``2Mi
`2 +?BM; 7Q` i?2 /` r2` ? M/H2 /m`BM; i?2 M2ti `QHH@QmiVX h?
? b H2 `M2/ #Qmi i?2 +mi`2Mi`2 TQ7 QBM?Bb T`Q+2bb 7Q` i?2 M2ti
i+1X AM Qm` 2tT2`BK2Mib- r2 b?Qr i? i mbBM; Qm` T`QTQb2/ TT
+QKTH2i2 /B772`2Mi K MBTmH iBQM i bFb BM 72r2` BMi2` +iBQM
`i # b2HBM2bX

9Xk S`Q#H2K 6Q`KmH iBQM

q2 +QMbB/2` b2iiBM;b BM r?B+? `Q#Qi `K Bb ;Bp2M i?2 `2r `/ 7m
i bF- M/ i?2 `Q#Qi Kmbi H2 `M iQ QTiBKBx2 i?Bb `2r `/ rBi?Qmi `
2MpB`QMK2MiX JQ/2H@7`22 `2BM7Q`+2K2Mi H2 `MBM; TT`Q +?
T`Q#H2Kb b2iiBM;bc ?Qr2p2`- +m``2Mi TT`Q +?2b Q7i2M i F2 i?Q
iQ H2 `M #2M+?KR;9NXbFbQ (H2 `M i?2b2 b K2 i bFb BM 72r2` BMi2`
T`2b2Mi `2BM7Q`+2K2Mi H2 `MBM; TT`Q +? r?2`2 i?2 `Q#Qi `K
TH +2/ r vTQBMibX

J.SX _2BM7Q`+2K2Mi H2 `MBM; b22Fb iQ K tBKBx2 i?2 2tT2+i2/ +
7BMBi2@?Q`BxQM J `FQp .2+Mb=BQM;S`r;Q;+2ibX U2.2SV Bb i?2
rQ`H/ bi i2a 2MA/ Bb i?2 `Q#Qi `Köb +iBQMX _2im`MBM; iQ Qm` K
Q7 QT2MBM; s B`Mr2H-m/2b i?2 `Q#Qiöb TQb2 M/ i?2 TQbBiBQM M
/` r2`- aMB/ Bb i?2 `Q#Qiöb 2M/@2772+iQ` p2H?Q+`Q#Qi i?2 +2BpB2K b2ir2`

r(s^t) M/i` MbBiBQMb #2ir22M bi i2b #sb2= f(s^t, a^t)?2 hv?M2bk2B/+bM KB+b

`2mMFM,Qi?M2`Q#Qi/Q2b MQi? p2 ++2bbiQ KQ/2HQ7?QrBib2M

772+ii?2/BbTH +2K2MiQ7i?2/` r2`Q`Qi?2`2MpB`QMK2Mip `B

i? ii?2 `2r `/7mMS+!BRQ BMFMQXM6Q` BMbi M+2-i?2 `+Q#Qi Q/#b2`p2b

ibii2br?2`2i?2/` r2` Bb QT2M UBX2X-i?2/` r2`öb/BbTH +2K2

h?2 `Q#Qi `2T2 i2/Hv ii2KTibiQ +QKTH2i2 i?2 b K2i bF BM Bib 2

i?2 J.SM X 1 +? BMi2` +iBQM UBX2X- 2 +? 2THBiBQK/2bV2HTbXb"2Qr`22iQ

BMi2` +iBQMb i?2 rQ`H/ `2b2is^0 2QS i?2 BX2X- b?2i` r2` Bb +HQb2/

`Q#Qi `2im`MbiQ Bib ?QK2#T2Qib2iBQQ MHVMXmK2#i2` Q7 BMi2` +iBQMb-

MmK#2` Q7iBK2b i?2 `Q#Qi+ M ii2KTiiQ T2`7Q`K i?2 i bFX

_2;`2iXm`BM;2 +?BMi2` +iBQM i?2 bvbi2K pBbBib= fs^0;:D2,s^H-iQ`v Q7 r

bm+?i? Bb i?2 bvbi2K i` D2+iQ`v i?2 bQi?2 ?2+iBQXM U2K2K#2`BM;i? i

r(s) Bb i?2 `2r `/ i ;Bp2M bi R(-)=2 P /2 7Bs)M2b i?2 iQi H `2r `/ +`Qbb

i` D2+iQX`Pm` Q#D2+iBp2 Bb iQ B/2MiB7v i` D2+iQ`B2b i? iKBMBK

T`BQ` rQ`)F-br2 /27BM2 i?2 `2;`2i b,

$$REG(K) = \sum_{k=1}^{K} R(\ ) \quad R(\ ^k) \qquad U9XRV$$

r?2`2 Bb i?2 #2bi@+ b2i` D2+iQ`v i? iK tBKBx2b i?2 iQi H `2r `/

7mHHv QT2Mb i?2 /` r2`VX AMimBiBp2Hv- KBMBKBxBM;`2;`2i K2

+QKTH2i2 i?2 /2bB`2/i bF BM b 72r BMi2` +iBQMb b TQbbB#H2X

H2 `MBM;iQ #2T` +iB+ H QM `2 H@rQ`H/ `Q#Qi `Kb-r2 M22/K2i

`2;`2i 7`QK 1[mVBrQ?BM 72r BMKiX` +iBQMb

9Xj _2BM7Q`+2K2Mi G2 `MBM;rBi?a2[m2MiB

Pm` BMbB;?i Bb i? i K Mv K MBTmH iBQM i bFb 7Q` `Q#Qi `Kb +
b2[m2M+2 Q7 ?B;?@H2p2H r vTQBMib H2ib mb T`2b2Mi /B772`2M
2t KTH2 Q7 QT2MBM;i?2 /` r2`, ?2`2 i?2 `Q#Qi `K URV KQp2b Bib
UkV ;` bTb i?2 ? M/H2- M/ i?2M UjV TmHHb i?2 /` r2` QT2MX Sm
`K +QKTH2i2b i?2 /` r2` i bF #v 7QHHQrBM; i` D2+iQ`v #2ir22M i
q2 rBHH bbmK2 i? i i?2 `Q#Qi + M KQp2 #2ir22M i?2 ;Bp2M r vT
+QMi`QHH2` 7Q` i` D2+iQ`v i` +FBM;X >2M+2- Q?2`2 2 Q +?H H2 2M
2 +? bm#b2[m2Mb Q i?TQB?2 i`Q#Qiöb KQiBQM KBMBKBx2 bi `2;`
r2 mb2 Qm` BMbB;?i iQ `27Q`KmH i2 `2BM7Q`+2K2Mi H2 `MBM; b
`K2/# M/BibX AM a2 2 iBQM i?2 bbmKTiBQMb #2?BM/ i?Bb 7Q`Km
BM a2+ 2 iQ 2tTHQ`2 i?2 i?2Q`2iB+ H BKTHB+ iBQMb M//2`Bp2 b
6BM HHv- BM a2 2 iB2QM2Mi Qm` H;Q`Bi?K 7Q` H2 `MBM;r?2`2 iQ TH
r vTQBMi HQM;i?2 `Q#Qiöb i` D2+iQ`vX

9XjXR _27Q`KmH iBQM b a2[m2M+2 Q7 JmHiB@ `K2

AMi`Q/m+BM;?B;?@H2p2H r vTQBMib H2ib mb T`2b2Mi /B772`2M
7Q`+2K2Mi H2 `MBM;T`Q#H2K 9/XkH M/ 2 i? BM a2 + 7BQ`KmH iBQM i?2
?B;?@H2p2H +iBQM Bb i?2 +?QB+2 Q7 r?2`2 iQ TH +2 i?2 M2tir v
`Q#Qi `KVX b r2 rBHH b?Qr- i?Bb H2 /b iQ b2[m2M+2 Q7 +QMiB
r?2`2 2 +? # M/Bi b22Fb iQ QTiBKBx2 i?2 M2tir vTQBMi HQM;i?2

6`QK +iBQMb iQ h` D2+iQ2 B2 h`X i?2 bi i2 Q7 i?2 `Q#Qi `KX h?2 `
bi i2 Bb bm#b2i Q7 i?2 sr Q`mH/?biS2 i2S X 6Q` 2t KTH2-mH/ #2 i?2
TQb2 Q7 i?2 `Q#Qiöb 2M/@2772s+iQ`mH// BM THm2 i?2 HTQbBiBQM

/BbTH +2K2Mi Q7 i?2 /` r2`X h?2 `Q#Qi `K ? b s_R/XB`2mi +MQMi?2`H Q
r v- i?2 `Q#Qiöb 2M/@2772+iQ` M/ ;`BTT2`X

lM/2` Qm` T`QTQb2 $s_R$ BT`rQvTQ+BMM/ i?2 `Q#Qi `K +QKTH2i2b Bib i
KQpBM; i?`Qim D?2+iQ`v Q7 X v*TQMBMib 2` Qm` `mMMBM; 2t KTH2 Q
/` r2`, i?2 `Q#Qi +QmH/ T2`7Q`K i?Bb i $s_R^1$ Fr#2`K2Qi?2 MQ#Qi biBi2b i?2
/` r2`? M/H2- M/i? s_R^2 Mr?2bi2i2?2 `Q#Qi `K KQp2b r viQ TmHH i?2 /`
q2 i?2`27Q`2 /27BM2 i?2 `Q#Qiöb `2 72b 2 [m+2Mi +2DQ7 iQ2`bB`2/ r vTQ
= f s_R^0;::: ; s_R^T gX h?2 `Q#Qi `K ? b KTtBKvmTKQ7Mib BM Bib i` D2+iQ`v
+?QB+T2BQb7H27i iQ i?2 /2bB;M2`c ?QrT2 $s_R^1$H-brQ2 i+?QiMib?i2 MBMK#2` Q7
r vTQBMib Bb H2bb i? M i?2 iQi H MmK#2` Q7 iBK2bi2Tb BM QM2 I
/2MQi2b bMBTT2iQ7 ir?Bi?r vD2+BQMib VX 6Q` 2t KTBH2i` D2+iQ`v
bMBTT2i rBi? Dmbi s_R^1M2M/vBTQBMi D2+iQ`v bMBTT2i rBi? irQ r vTQ
i? i_2 = f s_R^1; s_R^2 gX

Pp2` H/H2-7BM2b `272`2M+2i` D2+iQ`v i? ir2r Mii?2`Q#Qi `K iQ
i` D2+iQ`v r2 bbmK2 ++2bb iQ HQr@H2p2H `Q#QiKQM2`iQ?2H2` i
`Q#Qi `K HXQhM?2`2 `2 p `B2iv Q7 `Q#Qi +QMi`QHH2`b 7Q` 7QHHQ
(N9- M/Qm` TT`Q +?BbMQiiB2/iQ Mv bT2+B7B+ +QMi`QHH2` -
mb2 BKT2/ M+2 (N3)XQMi`QH (+iB+2- BKT2/ M+2 +QMi`QH + mb2b i?2 `
BMi2`TQH i2 #2ir22M $s_R^1$ ?2r?BvHT2QB2MibBMBM; +QKTHB Mi B7 i?2 `Q#
+QMi +irBi? Q#D2+ib BM i?2 2MpB`QMK2MiX

6`QK lMFMQrM .vM KB+b iQ lMFMQrMB_p22rM`ib?Xi i?2 `Q#Qi `K ? b
+?Qb2M iQ `QHH@Qm2 iM2D2+iQi`vQ /2i2`KBM2 ?Qr 2772+iBp2Hv i
rBHH T2`7Q`K i?2 /2bB`2/i bFX Bib?2 `QQ@Qi2ip`2+HF+bQMi`QHH2` Qm
a U2X;X- 2M/@2772+iQ` p2HQ+BiB2b- QT2MBM; M/ +HQbBM; i?2 `

MQi QMHv i?2 `Qs#Qiöb bHHbiQ i?2 rQs`X/_b2im2`MBM; iQ Qm` 2t KTH2
KQpBM; i?2 `Q#Qiöb 2M/@2772+iQ` r v 7`QK i?2 /` r2` r?BH2 ?QI
KQ/B7B2b i?2 /BbTH +2K2MiQ7 i?2 /` r2`X ++Q`/BM;Hv- i?2 +QKT
= fs^0;:::;s^{H}g Bb 7mM+iBQM Q7 i?2 `Q#Qiöb i` D2+iQ`v

$$= g(s^0; \ ) \qquad \text{U9XkV}$$

>2`g2/2T2M/b QM #Qi? i?2 mMFfMsQa) MMv M?2KBQ+bQiöb HQr@H2p2H +C
h?2 rQ`H/ bi `ibs^{0}BMMb/ii?2 `Q#Qi i F2b HQra@iHQ27Q2HH+QiBiQMXb2+iQ`v
q2 Qp2`HQg/M?QBibiBQM 7Q` i` D2+g(s^0; $_i$) bQMmBTT2bbi,?2 b2[m2M+2 Q7 r
bi i?2b r?2M i?2 `Q#Qi 2t2+mi2b i?2 i` $_i$XD2+iQ`v bMBTT2i

h?2 `Q#Qi /Q2b MQi FMQr ?Qr BibQHHMKi`TDiQ+iQ`M;2b BM i?2 rQ`H/
6`QK Qm` 2t KTH2, B7 i?2 `Q#Qi TH Mb s^1_RiQM2i?2MQMKQir?2TQBMQBM
s^2_R - i?2 `Q#Qi /Q2b MQi FMQr #27Q`2? M/ r?2i?2` i?Bb KQiBQM rB
; BMbi i?2 /` r2`- Q` KBbb i?2 /` r2` HiQ;2i?2`X qBig?Qr2i FMQrB
`Q#Qi + MMQi MiB+BT i2r? i2772+ib Bib i` D2+iQ`v rBHH ? p2 QI
`Q#Qi + M K2 bm`2 i?2 `2r `/ 7Q` i` D2+iQ`B2b Bi ? b T`2pBQmbH
7QHHQMb Q#b2`p2b i?2 b2[m2M+2 Q7 `2-bm?2iBQM#;QriQ`bHi/QbiH2`2r `/ B
R g(s^0;) = R( )X aBKBH `Hv- 7i2` i?2 `Q#Qi 2t2+m$_i$2bBibi`K2D2+mQ2`v bM
`2r `/ Bbg(s^0; $_i$) X q2 rBHH r`Bi2 i?2b2 i` D2+iQ`v `2r `/b KQ`2 +QKT

$$R\ (s^0; \ ) = R\ g(s^0; \ ) \qquad \text{U9XjV}$$

r?2`2= f $_1$; $_2$;:::; $_T$g Bb b2`i2Q7`/ T ` K2BM/bm+2/ #v i?2 mMFMgQXrM K TTI
>2`2 T ` K2i2`Bx2b iQ i?2 `2r `/ 7Q` KQpBM; 7`QK is^1_R2-bM/ibi i2iQ
T ` K2i2`Bx2b i?2 `2r `/ 7Q` KQpBM1;i7Q`QKTQvBTMQi?2MiQ+Q2b MQi

BMBiB HHv FMQr i?2b2 ;2`r2ìm TM`BKM2;ii2Qb Qm` 2t KTH2- ii?2 7B`bi B

`Q#Qi /Q2b MQi FMQr ?Qs$^{i}_{R}$ KQQ$^{i}_{R}$BMB;7HQ7K72+ii?2 /` r2`öb /BbTH +2

JmHiB@ `K2/ " M/BBMX; r vTQ$_{R}$BMMb `2r `/ T ` K2-i2`2b+ M 2tT`2bb

Qm` T`Q#H2K b2bi2E[m2Mb+2 Q7 +QMiBMmQmb UKJm"HMX@M`K2/i?#BM/Bi

7Q`KmH iBQM i?2 `Q#Qi H2 `MQ?2r vTQBMbiìm+BK2X 1 +? J " BM

b2[m2M+2 +Q``2bTQM/b iQ /B772`2Mi r vTQBMi, BM i?2 7B`bi J

s$^{1}_{R}$- M/iB@Mi? J " i?2 `Q#Qi H2 `M$_{R}$bXrJvQT`Q2B7Qi`K HHv- 2 +? BBM/BpB/m

Bb /27BM2/ #v,

Ç h?2 +QMiBMmQmb bT +s$_{R}$ Q7 $_{R}$`Q#Qi bi i2b

Ç h?2 +QMiBMmQmb bT +2 Q7 $_{i}$2r $_{i}$/ Q``i?K2i2`MbBiBQM 7`QK r vT

i 1 iQ r vTQBMi

Ç T`BQ` Qp2` i?2 `2r `/ T ` K2$_{i}$2`B$_{i}$(b)m+? i? i

h?2 `Q#QiQT2` i2b rBi?BM 2p2`v J " 7Q` 7Bt2/MmK#2`Q7BMi2`

iQ i?2 M2ti J "X "2HQr r2 Qp2`pB2r #Qi? bi ;2b Q7 i?Bb T`Q+2bb

i` D2+iQ`vX q2 T`2b2Mi KQ`2 /2i BH2/ H;Q`Bi?K 7Q` bQHpBM;

a2+iB9QXJX 9

qBi?BM J "bAXK ;BM2 i?2 `Q#Qi Bb QT2` B$_{i}$BMB;XB2X?-BiM?2J `Q#Qi Bb i`v

iQ /2i2`KBM2 r?2`2 iiQ@T?Hr+v2TiQ?2BMiVX .m`BM; M BMi2` +iBQM i?2 `

TH vb # M/Bi `KX JQ`2 bT2+B7B+ HiH@vi-i?2vTQ#BQMi/b2tH2+mib2b?2

i?2 i` D2+iQ`v$_{i}$bXMB7T2`2ii?2 i` D2+iQ`v Bb +QKTH2i2-i?2 `Q#Qi K2 b

`2r `R$_{i}$(s^{0}; $_{i}$) T ` K2i2`Bx2/ #v i?2 mMFMXQrM?B2bB+?i+bH2 `2T2 ib i 2

BMi2` +iBQM i?2 `Q#Qi i2bib M2s$^{i}_{R}$+?MQ/B?2MQQ#bv2TQ?2BMi i?2 `2r `/ T

i?2 +Q``2bTQM/BM; i` D2X+iQ`v bMBTT2i

"2ir22M J "bXb i?2 `Q#Qi QT2` i2b BB?iBHM2 J`"Mb r? i rs$_R^i$vTKQtBQMi
BKBx2b Bib K2 bm`2/ `2r `/X q2 7Bt i?Bb r vTQBMi BM TH +2 r?2
i?2 M2ti JB$_{i+1}$" X JQ`2 ;2M2` 7HB2vx2i?2 bi?2i?2Qv#Qi mb2b s$_R^i$Qb+Q?QQb2
i? i rBi?BMB$_{i+1}$" i?2 `Q#Qi QMHv 2tTHs$_R^{i+1}$2Xb hQv#QBM/ i` D2+iQ`B2b
KmHiBTH2 r vTQBMib i?2 `Q#Qi Bi2` i2b i?`Qm;? i?2 T`2pBQmbHv
iQ Qm` 2t KTH2, B$_1$2 i?2T`bQB#Qi H2 `M2/iQ `2 +? i?B$_2$2 i?2r2Q#MQ/iBM
H2 `M2/iQ ;` bT i?2 ? M/H2X q?2M i?2 `Q$_R^3$#BQM2JtBH-Qi`2b2+vTQvBMi
= fs_R^1;s_R^2;s_R^3g rBHH 7B`bi KQp2 iQ$_R^1$iV?2M/ ;r2`bU i?2 s_R^2MXH2 U

9XjXk bbmKTiBQMb

"27Q`2r2 M Hvx2i?Bb T`QTQb2/J "7Q`KmH iBQM r2r MiiQ+H `B
Qm` TT`Q +?X 6B`bi-r2 bbmK2i? i i?2 `Q#Qi `K + M +QKTH2i2
b2[m2MT+2r QT7QBMibX h?Bb bbmKTiBQM Bb pBQH i2/ r?2M i?2 /2
r vTQBMib UBX2X- i?2 `Q#Qi + MMQ Ti=QT2MQ i?2 2Mri2`2r`?Q#MQi Bb 7
rBi? i bF i? i /Q2b MQi #`2 F /QrM BMiQ r vTQBMib UBX2X- i?2
BMp2`i2/ T2M/mHmKVX

a2+QM/- r2 bbmK2i? ir(s)?2Bb2+Q`KTQb2/ Q7 KmHiBTH2 HQ+ H K tB
K tBK +Q``2bTQM/b iQ bi ;2 Q7 i?2 i bF i? i + M #2 +QKTH2i2/ #v
2t KTH2-i?2 `2r `/ 7mM+iBQM 7Q` QT2MBM; /` r2` +QmH/BM+Hm
? M/H2-r?2i?2`i?2 ? M/H2 Bb ;` bT2/- M/i?2 /BbTH +2K2MiQ7i?
Bb pBQH i2/ r?2M i?2 `2r `/ 7mM+iBQM /Q2b MQi 2M+Q/2 M2+2bb
i?2 `Q#Qi M22/b iQ TT`Q +? i?2 /` r2` ? M/H2 7`QK #Qp2iQ QT2M
b+Q`2b i?2 /Bbi M+2 iQ i?2 +2Mi2` Q7 i?2 ? M/H2 i?2 `Q#QirBHH
i i?2 +2Mi2` Q7 i?2 ? M/H2 U M/ MQi TT`Q +? Bi 7`QK #Qp2VX

h?2b2 bbmKTiBQMb HBKBii?2ivT2b Q7i bFb 7Q`r?B+?Qm`b2[m2
M/ HbQ TH +2 M BM+`2 b2/2KT? bBb QM `2r `//2bB;MX >Qr2p2
2tT2`BK2Mib p `B2iv Q7 K MBTmH iBQM b+2M `BQb biBHH b iB
HbQ MQi2 i? i miQK i2/ `2r `//2bB;M Bb M QM;QBM; `2b2 `+? i
K2i?Q/b bmH/ #2 H2p2` ;2/ iQ KBiB; i2 Qm`b2+QM/ bbmKT

9XjXj GQr2`"QmM/b QM _2;`2i

AM a2+ BQ`2 `27Q`KmH i2/ `2BM7Q`+2K2Mi H2 `MBM; rBi? r vTQ
J "bX >2`2 r2 2tTHQ`2 i?2 i?2Q`2iB+ H Qmi+QK2b Q7 i?Bb 7Q`KmH
T `2 HQr2`#QmM/b QM `2;`2i b/2 M 2?2BMm1 bmBMBiQ2b i M/ `/J.S
7Q`KmH iBQM M/Qm`bT2+B H + b2 J "7Q`KmH iBQMX h?2b2 HQ
T2`7Q`K M+2, BX2X- B7 r2 B/2MiB7v QTiBK H H;Q`Bi?Kb 7Q`#Q
?Qr[mB+FHv M/277B+B2MiHv rBHH i?2`Q#Qi H2 `M iQ +QKTH2i
2tBbiBM; M HvbBb- r2 +QMbB/2` b2iiBM;b r?2i 2#Qi iB?2M bi i2bT
`2/Bb+X2 i2M Qm`2tT2`BK2 MXSMUa2 ri2BiQ2M bi i2bi r?2i?2`i?2b2 i?2Q
`2bmHib 2ti2M/iQ +QMiBMmQmb bi i2@ +iBQM bT +2bX

.Bb+`2i2 LQi iBQ`2 MX#2 i?2 MmK#2` Q7 jSjiB#Q`2 i?2 MmiK#2` Q7 rQ`H
bi i2b- MjSRj H2 i?2 MmK#2` Q7 `Q#Qi bi i2bX Bbbi?2 iBK2/?2Q- BxQM
QM2 BMi2` +KBBQbMi?2/iQi H MmK#2` Q7 BMi2` +iBQ`2 `Q#QBM 2
+ M b2H2+i Mv SjRX2 >72 Q7 K2- 7Q` QM2 KmHiB@ `jSRj/ #BM+B2i?2`2
`KbX "2+ mb2 r2 7Bt i?2 +?QB2M?2`KiBMMbB'iBQMBiM;-iQ-`JQ'bb
i?2 b2[m2TM J2"Q7?2 `Q#Qi `2 bQMb QTp2SRj/Qb+H`2Qi2 `KbX

_2;`2i "QmM"/b X2+F M/ *2b @N"BBM2+MiB7B2/ HQr2`#QmM/QM `2;`
H2 `MBM; H;Q`Bi?K BM M J "X q?2M TTHB2/iQ Qm`9XjXR2MiB

i?Bb HQr2` #QmMR/E#G2(+)QK2bK,T jS$_R$j X

Pi?2` `2b2 `+? ? b B/2MiB7B2/ HQr2` #QmM/b QM i?2 `2;`2i 7Q` Mv

`Bi?K i? i `2T2 i2/Hv BMi2` +ib rBi? MBXM6?2M?QTBHBQ2MiQ.S(m` J.

M 7`QK a2+9XBkQ?Bb HQr2` #QmMR/E#(2(+)QK2bK,H ^{2}jSjjAj X Pb# M/ M/

o M _Qv +QMD2+im`2 i? i i?Bb HQr2` #QmMN/ Bb mMBKT`Qp #H2 (

h?2b2 `2bmHib [m MiB7v i?2 HQr2bi `2;`2i UBX2X- i?2 #2bi T2`7Q`

#Qi? T`Q#H2K 7Q`KmH iBQMbX Smi MQi?2` r v- i?2b2 #QmM/b i

MmK#2` Q7 BMi2` +iBQMb i?2 `Q#QirBHH M22/ #27Q`2 Bi + M +QK

MQiv2i+H2 `r? i H;Q`Bi?KbrBHH +QMbBbi2M+v `2 +?i?2b2 HQr2

i?2 HQr2` #QmM/b /Q2b T`QpB/2 i?2Q`2iB+ H DmbiB7B+ iBQM 7Q

T`Q#H2K b M JUSM/ bQHp2 mbBM; bi M/ `/ `2BM7Q`+2K2Mi H2 `M

b2[m2M+2 QB7UJ M/ bQHp2 mbBM; Qm` T`QTQb2/- i?2 HQ+2VXQbM/

7Q` Qm` J " 7Q`KmH iBQM Bb H2bb i? M i?2 J.S HQr2` #QmM/ r?2M

TjS$_R$j < H ^{2}jSjjAj U9X9V

q2 T`2pBQmbHTv</ 2H7BMi2/j jSj X >2M+2- 1[m 9XBQM;;U2bib i? i BM

b+2M `BQb r?2`2 Qm` bbmKT 9BXQXTkT Fi vQK i?a2 Bi/2QHMT2`7Q`K M+2 i

H2 `MBM; QM2 r vTQBMi i iBK2 Bb #2ii2` i? M i?2 B/2 H T2`7Q`

TQHB+vX

9XjX9 TT`QtBK i2 aQHmiBQM rBi? SQbi2`BQ` a KTHE

AM b2iiBM;b r?2`2 i?2 `Q#Qiöb i bF + M #2 #`QF2M /QrM BMiQ b2[

Q`2iB+ H M HvbBb bm;;2bib i? i i?2 J " 7Q`KmH #2BMQ7 7+BQKHa2+2B2

T`QTQb2 M TT`QtBK i2 bQHmiBQM iQ i?Bb b2[m2MiB H J " i? i +

iQ`v QM2 r vTQBMi i iBK2X Pm` TT`QtBK i2 iBQM bi K2 #2 bi2 BQM +
7Q` KmHiB@ `K2/ # M/BX h?Q2 #+Q2`K2 (B/2 BM TQbi2`BQ` b KTHBM; B
/Bbi`B#miBQM Qp2` i?2 mMFMQrM `i22 +/?TBi2K2iB2QM- i?2 `Q#Qi b
p Hm2 7Q`7QK i?2 TQbi2`BQ` M/ i?2M `QHHb@Qmi i?2 # M/Bi `K
R X " b2/ QM i?2 K2 bm`2/ `2r `/ 7`QK i?Bb `QHH@Qmi- i?2 `Q#Q
Qp2` M/ i?2M `2T2 ib i?2 T`Q+2bb mbBM; i?2 M2r TQbi2`BQ`X lM7
`2+iHv TTHv TQbi2`BQ` b KTHBM; #2+ mb2 Qm` bi i2 M/T ` K2i2
?B;?@/BK2MbBQM HX AMbi2 /- Qm` H;Q`Bi?K TT`QtBK i2b i?2
M2Mb2KQ#7H`22r `/ KQ/2Hb(("2HQr r2 2tTH BM ?Qr r2 H2 `M i?Bb 2Mb
J " B_i - M/ HbQ ?Qr r2 7`22x2 i?2 H2 `M2/ r2B;?ib r?2M i` MbBiBQ
B_{i+1} X

H;Q`Bi?K2X2 H;Q`B7?Q`K Qm` T`QTQb2/ TT`Q +?X Pm` K2i?Q/ Bb +
K BM T `ib iQ KB``Q` i?2 bi`m+im`2 Q7 b2[m2MiB 9+ KXXRBiB@M`K2/ #
;Bp2M J " i?2 `Q#Qi TT`QtBK i2b TQbi2`BQ` b KTHBM; i?`Qm;?
KQ/2Hb- M/ b2H2+ib i?2 M2ti r vTQBMi iQ K tBK2Bix2 2M2b2biBK i2
i?2 `Q#Qi b p2b i?2b2 i` BM2/ `2r `/ KQ/2Hbc /m`BM; 7mim`2 J "b
iQ i?2 b p2/ KQ/2Hb iQ /2i2`KBM2 i?2 T`2pBQmb r vTQBMib HQM;

qBi?BM J "bX i?2 bi `i Q7 B J i?2 `Q#Qi BMBiB HBx2b N `M2 r2 Mb2K#H2
KQ/2Hb 4U H6BVX2b ?2b2 `2r `/ KQ/2Hb 2biBK i2 i?2 mMF $(s^0_{i,i})$ M `2r `/ 7
7`QK 1[m 9BXQXMhU?Bb 2Mb2K#H2 Q7 `2r `/ KQ/2Hb TT`QtBK i2b i?2 T
Qp2`X h?2 `Q#Qi b KTH2b 7`QK i?Bb 2Mb2K#H2 iQ 2biBK i2 i?2
BMi2` +iBQM- UHMB/MT2THB2b +QMbi` BM2/ QTiBKBx iBQM S_R^i iQ B/2MiB
i? i K tBKBx2b i?2 b KTH2/ 15 2 16V XUHB2M`Q#Qi i?2M `QHHb@Qmi i?
i` D2+iQ`B M i?2 2MpB`QMK2Mi mbBM; Bib HQ7r@18V2X p2b +`Q+MQ`QHH2
i?2 BMBiB H rQ`H/ bi i2- i?2 `Q#Qiöb i` D2+iQ`v Q7 r vTQBMib- I

H;Q`Bi?KGR `MBM; q vTQBMib pB SQbi2`BQ` a KTHBM;

R,AMBiB HBx2 #m772` R7 fg2r `/ KQ/2Hb

k,AMBiB HBx2 r viT=QBMi BM/2t

j, r?BHi<2T /Q

9, i i+1 . h` MbBiBQM iQ M2tir vTQ

8, AMBiBN HBx2/ KQ/2Hb rBi?$_{i;1}$;2:B$_{;i;N}$?ib

e, AMBiB HBxD2 fgi b2i

d, 7Q2 +? BMi2` +iBQBM/BQM J "

3, J2 bm`2 rQ`H/ bis^0`i bi i2

N, AMBiB HBx2 i`fgD2+iQ`v . "mBH/i` D2+iQ`v

Ry, 7Qi`=1; ;i 1 /Q

RR, s^j_R `;K s_R $\frac{1}{N}\sum_{n=1}^{N} R_{j;n}(s^0;(;s_R))$

Rk, $(;s^j_R)$. //T`2pBQmb r vTQBMib

Rj, 2M/7Q`

R9, a KTH2 QM2 Q` KQ `2mBMB/BQ`2k

R8, s^i_R `;K s_R $R_{i;n}(s^0;(;s_R))$

Re, $(;s^i_R)$. //i@i? r vTQBMi

Rd, _QHH@Qmi i`BDM2J+iQ`v

R3, J2 bm`2 `2r 7Q` / iDb2i(s^0; ;R)

RN, 7Q2 +? `2r `/ KnQ//Q2H

ky, $\sum_{(s^0;;R)2D}$ $kR_{i;n}(s^0;)$ Rk

kR, lT/ i2 r2B;?$_{i;n}$ibQ KBMBKBx2 HQbb

kk, 2M/7Q`

kj, 2M/7Q`

k9, R $(_{i;1};::: _{i;N})$. a p2 H2 `M2/`2r `/ KQ/2H

k8,2M/r?BH2

r?2i?2`i?2/` r2`r b QT2M2//m`BM;i?2 BM2i?2i`BQ#QV`kTA/MiHBM2b

TQbi2`BQ`/Bbi`B##viBQBMBpM2;`2 +?`2r `/KQ/2HiQK i+?i?2K2 br

Qp2`` 2T2 i2/BMi2` +iBQMb-i?2 2Mb2K#H2 Q7 `2r `/KQ/2Hb b?

i`m2 `2r `/7mRM($s^0$;B)QXMh?Bb `2bmHib B^i_RMr?b+QKMibKBx2i?2i` D2+iQ

`2r `/ M/+QKTH2i2i?2 M2tibi ;2 Q7i?2i bF UBX2X-`2 +?7Q`i?2

QT2MVX AM T` +iB+2-b KTHBM; 7`QK M 2Mb2K#H2 Q7 KQ/2Hb

#2ir22M 2tTHQ`BM; M2r r vTQBMib M/2tTHQBiBM;i?2 #2bi T2`7Q

"2ir22M J "bXh?2 T`Q+2bb r2 ? p2 /2b+`B#2/ bQi@i?/2iv2TQBM2b i

HQM; i?2 i` D2+iQ`vX "mi r? i #Qmi i?2 =L`2Q B=Qmb\r vTQBMib
+QKTH2iBMB; Ji"?2 `Q#Qi b p2b i?2 2Mb2K#H2 Q7 `2r `/ KQ/2Hb Bi
24V q?2M i?2 `Q#Qi KQp2b QM iB-i?2 HM2pt2`J ;"2 i?2b2 b p2/ KQ/2Hb
BMi2` +iBQM iQ 7BM/ i?2 Ts R 2 xBQ-mQ FBMT;QbBM2i+ B 7B +12+Hi?2i HBM2
`Q#Qi HQ /b 2 +? 2Mb2K#H2 Q7 KQ/2Hb 17 iQ K- Bib1V#m 7/2i?2 7M`QK
TTHB2b +QMbi` BM2/ QTiBKBx iBQM 4 fs R ;b:Qs R H1 gX 7q2`2rKvTTQbBMxib
i? i i?2 `2r `/ KQ/2Hb mb2/ iQ b2H2+i i?2b2 T`2pBQmb r vTQBMib
MQi +QMiBMm2 iQ i` BM Q` KQ/B7v i?2 T`2pBQmb KQ/2HbX AMbi
i?2 2@i? r vTQBMi r?BH2 //BM; i? i M2r r vTQBMi iQ i` D2+iQ`v +
b2[m2M+2 Q7 T`2pBQmb J "bX

AKTH2K2Mi iBQM P2m`B2H bX `BK2Mib mb2/ NV=2M b2K#H2 Q7 KQ/2HbX
1 +? KQ/2H r b 7mHHv +QMM2+i2/ KmHiB@H v2` T2`+2Ti`QM rB
H2 Fv _2Gl +iBp iBQM 7mM+iBQMX h?2 `2r `/ KQ/2Hb r2`2 mT/ i2
` i2 Q:701 M/ Ja1 HQbbX hQ 7BM/ i?2 r vTQBMi i? i QTiBKBx2b i?
r2 TTHB2/ +QMbi` BM2/ QTiBKBx iBQM BM Qm` 2tT2`BK2Mib- r
a[m `2b S`Q;` KKBM; UaGaZSVX AM T` +iB+2 i?Bb QTiBKBx2` + M
iQ K2HBQ` i2 i?Bb Bbbm2 r2 mb2/ KmHiBTH2 BMBiB H b22/bX `2
?2`2 2,iiTb,ff;Bi?m#X+QKfoh@*QHH #f`H@r vTQBMib

9X9 "2M+?K `F aBKmH iBQMb

AM i?Bb b2+iBQM r2 2p Hm i2 ?Qr Qm` T`QTQb2/ TT`Q +? H2 `M
bBKmH i2/ 2MpB`QMK2MibX q2 T2`7Q`K2/ i?2b2 #Qm`BK2K#H2 Q7 `2r
H i2/ `Q#Qi 2MpB`QMK2MirBi? b2iQ7bi M/ `/K MBTXmH`QbbQM i b
i?2b2 #2M+?K `F i bFb r2 +QKT `2/ Qm` T`QTQb2/ TT`Q +? iQ bi i2

H2 `MBM; H;Q`Bi?Kb- M/K2 bm`2/i?2 `2r `/b UBX2X-i?2i bF T2
K2i?Q/X

AM/2T2M/2Mi o `Bq2#H+2QbKXT `2/ i?2 T2`7Q`K M+2 Q7 Qm`RT`QTQb2
UPm`VbiQ 7Qm` # b2HBM2bX 6B`bi- r2 BKTHa2KX2Mi2/Mb/QT7`iQt+BiQ`@-
K H TQHB+v QTiSBSKBVxRiyBXQ'MQbl?* M/SSP `2 KQ/2H@7`22 `2BM7Q`+
H2 `MBM; H;Q`Bi?Kb i? i#mBH/ TQHB+v 7Q`b2#Hb22+/iQ M;bHiQ2@H
sX

q2 HbQ2tia2M*/2M/SSPiQ bim/v i?2B` T2`7Q`K M7B2?r@2HM2pm2bHBMyTQB
BMbi2 /HQr7@H2p2XHq2iBBQHMHb`272` iQ i?2b2 KQ/Ba7B*2@rTTM`Q +?2b
SSP@xT aBKBH ` iQ i?2 Q`B;BM H H;Q`Bi?Kb- #Qi? K2i?Q/b H2
rQ`H/ bisK2bmi BMbi2 / Q7 QmiTmiiBMa,-HMQQa@*H@2rpT2MH/SSiPB@QMTb
QmiTmi i?2 M2tis$_R$ vi?QiBM2 `Q#Qi b?QmH/ pBbBiX q2 TTHB2/ i?2 b
+QMi`QHHP2m`bQBKMQp2 i?2 `Q#Qi `K #2ir22M r vTQBaMi*b@XrTi?2 Tm`T
M/SSP@rrTb iQ i2bir?2i?2` mbBM; ?B;?@H2p2H r vTQBMib Bb i?2
T`QTQb2/ TT`Qm+Q,mB72`7Q`Kb i?2b2 # b2HBM2b-i?Bb bm;;2bib
r2 /2p2HQT2/iQ H2 `M i?2 r vTQBMib Bb HbQ #2M27B+B HX

1MpB`QMKq2MmXb2/ i?2 #2M+?K `F i bFb /27BMi2Q/2BpMHmQ#iQ bim2BT2(@
7Q`K M+2 Q7 2 +? H;Q`B9?XKXUG2M27?2B`;Q#2Qi M22/b iQ TB+F mT #
6Q`i?a2 +iFbF i?2 `Q#Qi ? b iQ TB+F mT QM2#HQ+F M/bi +F BiQM
AM1mi bb2Ki?2Hv`Q#Qi TB+Fb mT Mmi M/7Bib BSiBQ+MF@TM2/@SLH2t+2
i?2 `Q#Qi TB+Fb mT /B772`2Mi Q#D2+ib BM i?2 2MpB`QMK2Mi M/
+QMi BM2`bX h?2b2 7Qm` i bKyz HHB7QQMbmQb2/i?2M`Q?#2Qiöb 2M/@27
HbQ bim/B2/irQ K MBTmH iBQM i bFb r?2`2 i?2 `Q#Qi /Dmbib BiI
.QQ`@bB?K2T`HQ2#Qi M22/b iQ `2 +? 7Q`i?2 /QQ` H i+? M/TmHHi?2/
+QKTHQ2Q`@Hi bF? i?2 `Q#Qi Kmbi im`M i?2 H i+? #27Q`2 Bi + M Q

6B;m`2 9Xk, aBKmH iBQM 2MpB`QMK2Mib M/`2r `/b 7Q` bBt K MI
K `F i bFb `2 i F2M 7`QR XQ#Q`b2mB-i?2i(bF i?2 BK ;2 QM i?2 H27i
2MpB`QMK2Mi b2imT- M/i?2 THQi QM i?2 `B;?i b?Qrb i?2 `Q#Qiö
`mMbX >B;?2`` `2r `/b BM/B+ i2 #2ii2`i bF T2`7Q`K M+2X h?2 / b?
+Q``2bTQM/ iQ i?2 2TBmQ7 2bQ?+2?//2/ M2r r vTQBMi iQ i?2 i` D
//BM;i?2b2 M2r r vTQBMib Q7i2M + mb2b b? `T BM+`2 b2 BMi?2
+? M;2 Q++m`b #2+ mb2 i?2 M2r r vTQBMi 2M #H2b i?2 `Q#QiiQ +
i bF, 2X;GXB7B2 `Q#Qi M22/b QM2 r vTQBMi iQ ;` bT i?2 #HQ+F M/
iQ HB7i i?2 #HQ+FX

2KT? bBx2 i? i i?2 BMBiB H rQ`H/ bi i2 7Q` 2 +? Q7 i?2b2 i bFb r

Q7 2p2`v 2TBbQ/2X 6Q` BMbi M+2- i?2 /QQ` r b TQbBiBQM2/ i /I

r2`2 TH +2/ i M2r HQ+ iBQMbX

S`Q+2/m`2 2K i?2 2tT2`BK2Mib r2`2 T2`@7QQ`K2/ mbFBM@;1KBF `Q#Qi

rBi? BKT2/ M+2 +QMi`QH BM 2M/@2772+iQ` bT +2XH1=1Q i bF ? /

iBK2bi2TbX +`Qbb HFm2MpB`@QrTK2SMib @rrT2`2i` BM2/iQ +QKTH2i

i?2 i bF mTb=2Mr;vTQBMib, i?2 HQr@H2p52+HB+Q2Mi2QTbH+Q2`2mb+2/r vTQB

1- M/ MQ5?i2BK2bi2TbiQ `2 +2Xr vTQB2Mib HB;?i KQ/B7B+ iBQMb iQ

`2r `/ 7mM+iBQMb +Q`mi?2b2K#MS B+F@ M/i@bFb #v2 BM+`2 bBM;i?

`2r `/b 7Q` +QKTH2iBM;2 +? bi ;2 Q7 i?2 i bF M/ //BM;T2M HiB2

Qp2`X

h #H2 9XR, 1p Hm iBQM `2bmHibX 97X-2r`2ib p2M/BiM2 BHM2 6BM2m`K2Q/2H
M/2p Hm i2/i?2B` T2`7Q`K2 TMB+b2Q/+2`bQXbq2 `2TQ`i p2b`i;M2/`2r `/
2``Q`X

h bF	J2?iQ/									
	a *		SSP		a *@rT		SSP@rT		Pm`b	
GB7i	44:31	2:06	17:58	0:34	0:46	0:02	0:22	0:06	6883	0:02
ai +F	12:20	0:42	3:04	0:19	0:01	0:0	0:86	0:09	7037	3:56
Lmi bb2K#H	9:51	0:14	8:54	0:33	0:10	0:01	0:74	0:09	19014	11:7
SB+F@ M/@6	5:59	0:24	1:37	0:10	1:11	0:17	0:24	0:05	8924	2:87
.QQ`@bBKT	9:72	0:23	4:58	0:20	0:01	0	1:67	2:59	6301	2:19
.QQ`@H i+?	15:89	0:17	6:64	0:26	0:14	0:01	0:29	0:03	4870	2:58

.2T2M/2Mi o `B #H2bXQ#Qiöb i bF T2`7Q`K M+2 r b K2 bm`2/ mb
i?2 `Q#Qi 2M+QmMi2`2/ i` D2+iQ/mv BQM7;rQ;`BHp/2bM 2T BbQ/2- r2 `2T
R( ) = $\sum_{s2}$ r(s)X >B;?2` `2r `/b BM/B+ i2 #2ii2` T2`7Q`K M+2X

_2bmHqi2Xb2T ` i2/ Qm` `2bmHib BMiQ irQ M/ib #H2X6BB;mX2
b?Qrbi?2 `2r `/b +?B2p2/ #v 2 +? KQ/2H@7`22 `2BM7Q`+2K2Mi H2
BM i?2 2MpB`QMK2MiX 1p2`v BMi2` +iBQ-M-LUB XB2K2 2ip22T`v-2 TMB/bQ/2
`2TQ`i2/i?2iQi H`2r `/ +`Qbbi? i2TBbQ/2X K i7Q2`H2 2M`iQ2#Q+iBQ K T
r2 i?2M b p2/ i?2 H2 `M2/ KQ/2Hb M/ i2bi2/ i?2B` T2`7Q`K M+2X
b2T ` i2 i2bib `2 HBb9 2XRB>M2`2 #H2 bBKmH i2/ `Q#Qi ii2KTi2/ iQ
2 +? K MBTmH 1UB QBMK2bFmbBM;i?2 KQ/2Hb Bi? /H2 `M2/7`QKi` B
i` BMBM;-/m`BM; 2p Hm iBQM i?2 TQbBiBQM M/ Q`B2Mi iBQM Q
` M/QKBx2/ ii?2bi `iQ7 2p2`v BMi2` +iBQMX

Pp2` HH-MQM2Q7i?2# b2HBM2br2`2 #H2iQ H2 `Mi?2i bFb+Q`
Q7 2TBbQ/2b p BH #H2 7Q`i` BMBM;X +`Qb*bHH2`M2/FbQ i2 Q+#b2
M/bQK2iBK2b;` bT i?2 /2bB`S2S PQ#MD2+ib2r?MB2/iQ `2 +? 7Q`i?2b2
q2 HbQ MQiBa2*/@?TT2`7Q`K2/r2HH ii?2bi `iQ7i` BMBM;-#miB
/`QTT2/ bi?2i` BMBM; T`Q;`2bb2/X q2 ?vTQi?2bBx2i? ii?Bb K

BMbi2 /Q7 H2 `MBM;QM2 r vTQBMib bi BK2 Hi M2QmbHv H2 `MB
/DmbiBM;#Qi? r vTQBMib Q7 i?2 i bFX h?Bb K v? p2 T`2p2Mi2/ i
r?B+? r vTQBMib r2`2 H2 /BM;iQ ?B;?2` `2r `/b, 2X;X- /B/ i?2 `Q#
TQbBiBQM Q7 r vTQBMi R Q` r vTQBMi k\

+`Qbb #Qi? i` BMBM; M/ 2Q mHm T2 i BQM K2/ i?2 # b2HBM X2 bX AM 6
?B;?HB;?Pm?`b / bm//2M DmKTb BM 2TBbQ/2 `2r `/X h?2b2 DmKT
2TBbQ/2b r?2`2 i?2 /Q#Qi r vTQBMib i` D2+iQ`vX 6QG 2?2 KTH2- B
`Q#Qi `K bQHp2/ i?2 KmHiB@ `K2 1#mM BM;7iQ 2 2TBbQ/2b- M/
i?2M i` MbBiBQM2/ iQ i?2 M2ti J " 2 i?2 `2 TBbQM2`2 b2/ i i?B
i` MbBiBQM #2+ mb2 i?2 `Q#Qi T`Q;`2bb2/ iQ i?2 M2 i?2 i
7B2 2TBbQ/2b i?2 `Q#Qi H2 `M2/ QM2 r vTQBMi iQ `2 +? M/;` bT
#HQ+FX ai `iBM; Q-K2 2TBbQ#Q2 TTHB2/ r? i Bi ? / H2 `M2/ iQ ;` b
M/ i?2M 2tTHQ`2/ Bib b2+QM/ r vTQBMi iQ /2+B/2 ?Qr iQ + ``v i? i
bBKmH iBQM `2bmHPmb`h;M2 7 B+B2MiHv H2 `M ` M;2 Q7 K MBT
HBKBi2/ MmK#2` Q7 BMi2` +iBQMb #v #`2 FBM; i?2 i bF /QrM B
H2 `MBM; i?2 i` D2+iQ`v QM2 r vTQBMi i iBK2X

9X8 _2 H@qQ`H/ 1tT2`BK2Mib

AM i?Bb b2+iBQM r2 2tTHQ`2 r?2i?2` Qm` T`QTQb2/ H;Q`Bi?K 2
K MBTmH iBQM i bFb 7`QK b+` i+? BM `2 H@rQ`H/ 2MpB`QMK2M
UPm`b rBi? i?2 #2bi@T2`7Q`KBM; # b2HBM 2 7`Q+KQbb`iBQ KBm7H2 BQM
K MBTmH iBQM i bFbX qBi?BM `2 H@rQ`H/ 2MpB`QMK2Mib rBi? M
H;Q`BM K2 /b iQ b?Q`i2` i` BMBM; T2`BQ/b M/ KQ`2 ++m` i2 i bF
`Q#Qiöb H2 `M2/ #2 ?i pBQ fb vQ2m`2m X#2fJJ1/@Hu7[9u

1tT2`BK2Mi H aq2 m QX M/m+i2/ Qm` `2 H@rQ`H7/@2.tQ 2`6BKM2FMi bQBMF
`Q#Qi `K Ub2 9 XBX;m2 2` BM2/i?2`Q#QiiQ T2`7Q`KirQ /B772`2MiK
HB7iBM; MGQBV7DM2+iQUT2MBM; .`/`r2 2`XUh?2 `Q#QPimmbM2/a * iQ
ii2KTiiQ H2 `M 2 +?i bFX

6Q` #Qi?i bFb i?2 2TBb=Q1 2 bBK2bi2TbX h?2 `Q#Qi mb2/ 2M/@2772
+QMi`QH iQ i F2 +iBQMb rBi?BM i2*2iM?2 BQ#QK2Qp2/ BM/2`2M/@27
M/;`BTT2`# b2/QM i?2 +iBQM QmiTmi #vPim?2bH?22 `Q#/QTiQH2B`+M2X/ c
irQ r vTQB7MiBK2bi2Tb 2 +?V- M/H2p2` ;2/i?2 b K2 HQr@H2p2H +
#2ir22M Bib bi `ibi i2 M/i?2 r vTQBMib HQM;XBib `272`2M+2i` D

i i?2 #2;BMMBM; Q7 2 +? 2TBbQ/2 i?2 `Q#Qiöb BMBiB H TQbBiBQ
Q7 i?2 Q#D2+i Q` /` r2` r b mMB7Q`KH6v@`#6MQ KBxM2 2XBiq2BM2H2+i2
i?Bb bK HH2`` M;2 iQ KBMBKBx2 i?2 MmK#2` Q7 i` BMBM; 2TBbQ
`mMMBM; BMiQ Bib DQBMi HBKBibX q2 HbQ TTHB2/ #QmM/ `v +
+QHHB/BM; rBi? i?2 i #H2 Q` ii2KTiBM; iQ KQp2B#72v Qm M2/Bii2rQ`F
b K2 `2r `/ 7mM+iBQM b BM `Q#Qi.`mB2i2rö2b/2 2TBB7M2/bFX2 MQ2 `2r `/
7mM+iBQM i? i 2M+Qm` ;2/ i?2 `Q#QiiQ ;` bT i?2 ? M/H2 M/ i?2M
bi` B;?i HBM2X

_2bmHqi2X7B`biK2 bm`2/ i?2 2TBbQ/2 `2r `/b i?`Q 9 X;b?2Qm bii?2BMBM
i` BMBM; `2r `/b p2` ;2/ +`Qbb i?`22 `mMb 7Q` #Qi?i bFb M/K
`2r `/ i?2 `Q#Qi +?BP2m2b mBi#Q13iiBK2ab* BMGB7iM/ #Q:75i
iBK2ab* BM` r2X

7i2` i` BMBM; +QKTH2i2/- r2 mb2/ i?2 `Q#Qiöb H2 `M2/ KQ/2Hb i
bm++2bb ` i2 7Q` #Qi?i bFbX PQm#Q`i b`TB2M2M/rBiB?7i2/ i?2 ` M/QK
TH +2/ #H1Q/2-F2BpMHm iBQ8QV Bm+b+U2bb ` i2 VX?m BQ#Qi`Hbv-#H2 iQ

6B;m`2 9Xj, a2imT M/ `2bmHib 7`QK Qm` `2 H@ 9XQ 8 `AMB7T2 `BK2M
`Q#Qi H2 `M2/ iQ TB+F mT .MrB2iBK+H2M`MB2M iQ QT2M /` r2` U Hb
6B;m`2 9XVX h?2 `Q#QiK2 bm`2/i?2 BMBiB H TQbBiBQM Q7 i?2 Bi2K
bi `i bis0ix2a * H2 `M2/ TQHB+v i? i Q7i2M KQp2/ iQ i?2 Q#D2+i Q7
+Q``2+iHv BMi2` +i rBi? i? i Q#D2+i Pm2`+biX2q`?2MQm#BMB Hi i` D2+iQ`v
r vTQBMib, i?2 7B`bi r vTQBMi ;` bT2/ i?2 Q#D2+i- M/ i?2M i?2 b
rBi? i? i Q#D2+i U2X;X- TB+F2/ i?2 Bi2K mT- TmHH2/ i?2 /` r2` QT
`2r `/ THQib +Q``2bTQM/b iQ i?2 2Q#QT Q//2 i?2 b2+QM/ r vTQBMi iQ
i` D2+iQ`vX

;` bT M/ i H2 biT `iB HHv Q7 i?2 H`mr2 BMi`B HbX "v +QMi` b

a * i?2 `Q#Qi r b M2p2` #H2 iQ +QKTH2i2 2Bi?2`i bF ;Bp2M i?2 H

9Xe amKK `v

AM i?Bb +? Ti2` r2 7Q+mb2/ QM KQ/2H@7`22 `2BM7Q`+2K2Mi H2

MBx2/ i? i K Mv Q7 i?2 2p2`v/ v K MBTmH iBQM i bFb i? i r2 r Mi

#`QF2M /QrM BMiQ b2`B2b Q7 ?B;?@H2p2H r vTQBMib U2X;X- `2

T`QTQb2/ 7` K2rQ`F 7Q` r vTQBMi@# b2/`2BM7Q`+2K2Mi H2 `MB

i bFb #v #mBH/BM; i` D2+iQ`v QM2 r vTQBMi i iBK2X Pm` F2v +
BM; i?Bb T`Q#H2K b b2[m2M+2 Q7 KmHiB@ `K2/ # M/Bib, Qm` i?
#2bi@+ b2 bQHmiBQMb iQ i?Bb # M/Bi 7Q`KmH iBQM rBHH QmiT2`
BMi`Q/m+2/ QM2 TQbbB#H2 H;Q`Bi?K 7Q` bQHpBM; i?2 b2[m2MiB
TT`Q +? H2p2` ;2/ M 2Mb2K#H2 Q7 KQ/2Hb iQ TT`QtBK i2 TQbi
i?Bb K2i?Q/ H2 `M2/ 2 +? bm#b2[m2Mi r vTQBMi iQ ;`22/BHv K tBK
7QmM/ i? i Qm` TT`Q +? QmiT2`7Q`K2/ +QKKQMHv mb2/ KQ/2H@
H;Q`Bi?Kb +`Qbb b2i Q7 bBKmH i2/ M/ `2 H@rQ`H/ K MBTmH i
rBHH 2tTHQ`2 KQ`2 +QKTHB+ i2/ i bFb i? i `2[mB`2 ?B;?2` MmK#

*? Ti2` 8

*QK#BMBM; _B;B/ :`BTT2`b rBi?

arBi+? #H2 /?2bBp2b

aQ 7 `- r2 ? p2 BMi`Q/m+2/ 7` K2rQ`F iQ H2 `M H i2Mi 2K#2//BM;b
M/ r vTQBMi@# b2/`2BM7Q`+2K2Mi H2 `MBM; H;Q`Bi?K i? i H2
H2 `MBM;i bFb BM M 2MpB`QMK2MiX AM Q`/2`iQ 2772+iBp2Hv H2
Q7 / BHv HBpBM;- i?2 `Q#Qi b?QmH/ #2 #H2 iQ K MBTmH i2 /Bp
2MpB`QMK2Mi- ` M;BM; 7`QK bK HH /2HB+ i2 Q#D2+ib bm+? b
Q#D2+ib bm+? b D ` Q7 Kmbi `/X AM i?Bb +? Ti2`- r2 BMi`Q/m+2
i? i +QK#BM2 i?2 + T #BHBiB2b Q7 `B;B/ M/ bQ7i ;`BTT2`b- 7QH
b? `2/ +QMi`QH TT`Q +? i? i T `iB HHv miQK i2b i?2 mb2 Q7 i?2
;`BTT2` M/ Qm` b? `2/ +QMi`QH 7` K2rQ`F- i?2 mb2`b + M H2p2` ;
K MBTmH i2 rB/2 ` M;2 Q7 Q#D2+ib Q7 / BHv HBpBM;X

8XR AMi`Q/m+iBQM

Pp2` R KBHHBQM /mHib BM K2`B+ bm772`BM; 7`QK T?vbB+ H /
T2`7Q`KBM; +iBpBiB2bNX7 AMBHQv /2BpiQMb(Bbi i?2b2 /mHib rBi?
HB72- bbBbiBp2 `Q#Qi `Kb KQmMi2/ QM r?22H+? B`b b?QmH/ #2
/B772`2Mi Q#D2+ib i? i i?2 mb2`b K v 2M+QmMi2` /m`BM; i?2B` /