L?Na>v$_9~$_!$%G!<%?Ej5!$*hS:FMxMQ5;=Q$rMQ$$$? **Java** 2>A[%^%7%s$N9bB.2=

=E ED Bg =u[†] >. @n MN J?[††] ;3 ED 9n <y[†]
8^ Eg @5 M5[†] Cf Eg 9/ I'[†††]
?9 bC 0l O:[†] IY ED bC <#[†]

Java %P%$%H%3!<%I$rD>@\<B9T9k>l9g$K!$L?Na>v$_9~$_!$%G!<%?Ej5!$*hS%G!<%?:FMxMQJI$N<jK!$KhCFI$NDxEY$N9bB.2=$,2DG=$+KD$$$F9M;!7?!%L?Na>v$_9~$_$O%9%?%C%/%^%7%s$NFCD'Kh$kL?Na?t$NA}2C$rM^$($k<jK!$G$"$k!%8z2L$rDjNLE*$KB,Dj9k$?$a$K!$L?Na>v$_9~$_$r9MN8$KF~l?%W%m%;%C%5$N9=@.$r2>Dj$7!$$3$N%W%m%;%C%5>e$G!$L?Na$N<B9T7k2L$rM=B,$9$k%G!<%?Ej5!!$L?Na$N<B9T7k2L$r:FMxMQ9k%G!<%?:FMxMQ$N8z2L$rB,Dj7?7k2L!$%G!<%?:FMxMQ$N<jK!$,%G!<%?Ej5!$N<jK!hj$b8z2LE*$G$"$k3H$,$o$+$C$?!%

High Speed Java Bytecode Execution Using Instruction Folding, Data Value Speculation and Data Value Reuse

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Masahiro Goshima,[†] Yasuhiko Nakashima,[†††] Shin-ichiro Mori[†]
and Shinji Tomita[†]

This paper describes the effectiveness of Instruction Folding, Data Value Speculation and Data Value Reuse against the execution of Java bytecodes. For a quantitative evaluation, we assumed a micro architecture equipped with some special purpose tables and facilities for Instruction Folding which can reduce the number of dynamic steps of instructions. On this execution model, we measured the effectiveness of Data Value Speculation which predicts the results of instructions, and that of Data Value Reuse which reuses the result of instructions. As a result, we show that Data Value Reuse is more efficient than Data Value Speculation.

1. O8aK

Java %P%$%H%3!<%I$r;HMQ9k>eGNLdBjE@HJCF$$$kNO!$$=$N<B9TB.EY$G$"$k!%3NLdBj$r2r7h$9$k9bB.2=$N$?$a$N<jK!$H7F!$L?Na>v$_9~$_!$%G!<%?Ej5!$*$h$S%G!<%?:FMxMQ$JIN<jK!$,9M$(il$k!%K\9F$GO3li$NJ}<0$NFCD'KD$$$F=R$Y!$%O!<%I%&%'%"Kh$k<BAu$r2>Dj7?>l9g$N8z2L$K$D$$$F=RYk!%2>OGO!$Java 2>A[%^%7%s$NFCD'$+$i9bB.2=$NI,MW@-$K$D$$$F=RYk!%3>OGO!$Java 2>A[%^%7%s>e$G<B9T5l$?L?Na$N=P8=IQEY$K4p$E$-9bB.2=$N<jK!$N8!F$$r9T$&!%9bB.2=<jK!$N8z2L$rDjNLE*$KB,Dj9k$?$a$K!$4>OGOL?Na>v$_9~$_$r9MN8$KF~l?%W%m%;%C%5$r9=@.$9$k!%5>O$G$O!$$3$N%W%m%;%C%5>e$G$N%G!<%?Ej5!$*hS%G!<%?:FMxMQ$N<jK!$NF0:nKD$$$F=RYk!%6>OGO!$3F9bB.2=<jK!$N8z2LrB,Dj7!$7>O$K$*$$$F9M;!$r9T$&!%

2. **Java** 2>A[%^%7%s

Java 8@8l$O!$JBNs6nF0$,2DG=$J%/%i%9$r4pK\$H7?%*%V%8%'%/%H;X8~7?%W%m%0%i%_%s%08@8lG"$j!$2DG=$J8B$j<BAu$K0MB8$9$kItJ,$,$J$$$h$&$K@_7W5l$F$$$k!%Java 8@8lKh$j5-=R$5l?%W%m%0%i%`$OJava %P%$%H%3!<%I$KJQ49$5$l!$MM!9$J<B9T4D6-$K$*$$$F<B9T$9$k$3$H$,$G$-$k!%<B9T4D6-$,%W%i%C%H%U%)!<%`$K0MB8$;$:!$$7$+$b0BA4@-$,9b$$$H$$$&FCD'Kh$j!$:#F|GOJava 8@8l$O%$%s%?!<%M%C%H>e$G9-$/;HMQ5lF*$j!$:#8e$^$9$^$9Ia5Z7F$$$/bN$H;W$olk!%

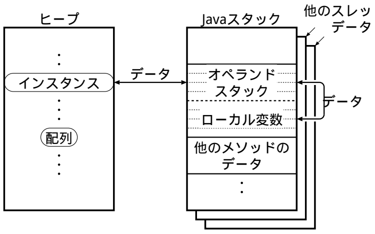
5F!$Java 2>A[%^%7%s(0J2<JVM)$O%[%9%H!&W

[†] 5~ETBg3XBg3X1!>pJs3X8&5f2JDL?.>pJs%7%9%F%`@l96
Division of Communications and Computer Engineering, Graduate School of Informatics, Kyoto University

[††] 5~ETBg3X9)3XIt>pJs3X2J
Department of Information Science, Faculty of Engineering, Kyoto University

[†††] 5~ETBg3XBg3X1!7P:Q3X8&5f2J
Graduate School of Economics, Kyoto University

%i%C%H%U%)!<%`$rA[Dj$7$F$$$ko1GO$J$$!%JVM$O!$FCDj$N%U%!%$%k!&U%)!<%^%C%H!$$9Jo$A%/%i%9%U%!%$%k!&U%)!<%^%C%H$N>pJs$N$_$rJ];}7F$*$j!$Java 8@8l$N>pJs$OJ];}$7$F$$$J$$!%/%i%9%U%!%$%k$H$O!$JVM $NL?Na(%P%$%H%3!<%I) $H%7%s%\%k!&F!<%V%k!$$JiS$KB>$NIU?oE*$J>pJs$rJ];}7?bNG"$k!%



?^1　JVM $N%G!<%?0h

JVM $,;HMQ$9$k%G!<%?0h$O?^1Nh$&$KBg$-$/3DNItJ,$+$i@.$k!%%*%Z%i%s%I!&%9%?%C%/$*hS%m!<%+%kJQ?t$O3F%a%=%C%IKh$K8GM-G"$j!$B>$N%a%=%C%I$+$i;2>H$9k3HOG-$J$$!%$^$?!$%R!<%W$O3F%a%=%C%I$@$1GJ$/!$3F%9%l%C%I4V$G6&M-$5lk!%

%*%Z%i%s%I!&%9%?%C%/!!JVM $NBgH>$NL?Na$O!$8=:_<B9TCf$N%a%=%C%I$N%*%Z%i%s%I!&%9%?%C%/$+$iCM$r<hF@!$1i;;$7!$F10l$N%*%Z%i%s%I!&%9%?%C%/$K7k2LrJV9=hM}$r9T$&!%%*%Z%i%s%I!&%9%?%C%/$O%a%=%C%I$K0z?trEO7!JVjCM$r<u$1<hk?aK$b;H$olk!%

%m!<%+%kJQ?t!!8=:_<B9T7F$$$k%a%=%C%IFbGN$_;HMQ$9kCMrJ];}7F$$$k!%$^$?%a%=%C%I8F$S=P$7$N0z?t$O3NNN0h$rMQ$$$F<u$1<h$k!%

%R!<%W!!%R!<%WO9YF$N%/%i%9!&%$%s%9%?%s%9!$G[Ns$N3djEvF$r9T$&<B9T;~$N%G!<%?0h$G$"$k!%

JVM $NL?Na%;%C%H$O!$%m!<%+%kJQ?t$N%m!<%I/%9%H%"!$1i;;!$7?JQ49!$%*%V%8%'%/%H$NA`:n!$%*%Z%i%s%I!&%9%?%C%/$N4IM}!$J,4t!$%a%=%C%I$N8F$S=P$7$*$h$S%j%?!<%s!$Nc30$N%9%m!<!$F14|$J$I$NL?Na$r4^$`!%

JVM $O!$7?IU1,6/$/!$$^$?<B9T;~$K<B9T5l$k%a%=%C%I$,7hDj5lkH$$$&FCD'$r;}$C$F$$$k!%3N$?$a!$Java 8@8l$+$i%P%$%H%3!<%I$r@8@.$9$kJava %3%s%Q%$%i$O!$%3%s%Q%$%k;~$N:GE,2=$r==J,$K9T$&$3H,G-$J$$!%$^$?JVM $O%9%?%C%/%^%7%s$G$"$k$?$a!$%*%Z%i%s%I!&%9%?%C%/>e$NCMN_$,A`:n2DG=$H$J$C$F$$$k!%$D$^$j!$%m!<%+%kJQ?t>e$NCM$O0lEY%9%?%C%/>e$KCM$r0\F0$7$J$1$l$P!$0\7$&$3$H$,$G$-$J$$!%%P%$%H%3!<%I$r5-=RDL$j$K<B9T$9$k$H!$IT!,MW$J%G!<%?$NA`:n$,H/@8$9$k$?$a!$<B9T$N9bB.2=$,Fq$7$$H8@$($k!%

3. 9bB.2=<jK!

$^$:!$%P%$%H%3!<%I<B9T;~$NL?Na$N=P8=IQEY$ND4::$r9T$$!$$=$NFCD'$K$D$$$FD4::7?!%

I=1$K!$SPEC JVM 98 1)K*$$$F!$<B:]$K<B9T5l$?L?Na$NFbLu$r<($9!%3N7k2Lhj!$%a%=%C%I$N8F$S=P$7!$$*hS!$%R!<%W$NFI$_=P$72s?t$,Hf3SE*B?$$$3H,o+$k!%$3li$NL?Na$O!$%*%Z%i%s%I!&%9%?%C%/>e$N%*%V%8%'%/%H$N%j%U%!%l%s%9$d!$%3%s%9%?%s%H!&%W!<%k$X$N%$%s%G%C%/%9$r85$K7F!$<B9T$9$k%a%=%C%I$r7hDj9kA`:n!$$*$h$S!$;2>H$9$k%U%#!<%k%I$N%"%I%l%9$r7hDj$9$kA`:n$r4^$`!%$3$l$i$NA`:nKO!$0lHIE*$KB?$/$N=hM};~4VrI,MWH9k!%

$^$?0"B3$9$k2 L?Na$N=P8=IQEY$rD4::7?7k2L!$%m!<%+%kJQ?t$+$i%9%?%C%/$X@Qs@CM$r<!$NL?Na$G;HMQ$9$k>l9g$,B?$+$C$?!%JVM $O%9%?%C%/%^%7%s$G$"$k$?$a!$%P%$%H%3!<%IH7FO3Nh&$JL?NaNs$HJCF7$^$&!%7+$7!$%m!<%+%kJQ?t>eNCMr%9%?%C%/$K@Q$`A`:n$r>JN,$9k3HKhj!$9bB.2=$,2DG=G"$k!%

5F!$$3li$NFCD'$rU^$($F!$%P%$%H%3!<%I$N<B9T$r9bB.2=9k$?$a$N<jK!$r0J2<$KNs5s$9$k!%

- %a%=%C%I8F$S=P$7$*$h$S%R!<%WFI$_=P$7;~$NBP>]%"%I%l%9$N7W;;$O!$A02s$NCM$rJ];}$7F*$-!$:FMxMQ9k3HKh$j9bB.2=$,2DG=G"$k!%
- %m!<%+%kJQ?t$r%9%?%C%/$X@QsG$+$i;HMQ9k>l9gKO!$%m!<%+%kJQ?t>e$NCMr=N^$^;HMQ$9k3HKhj9bB.2=$,2DG=$G$"$k!%$^$?!$%9%?%C%/>e$G9TC?1i;;$ND>8e$K%m!<%+%kJQ?t$X=q$-9~$`>l9g$K$b!$F1MM$K!$D>@\%m!<%+%kJQ?t$X=q$-9~$`$3HKhk9bB.2=$,2DG=$G$"$k!%3Nh&$J<j=g$r0J2<GOL?Na>v$_9~$_$H8F$V 2)!%

4. Java %W%m%;%C%5

4.1 L?Na>v$_9~$_$r9MN8$KF~l?4pK\9=@.

K\>OGO!$A0>O$K$*$$$F=RY?4pK\E*$J9bB.2=<jK!$r<B8=9k$?$a$N%W%m%;%C%59=@.$K$D$$$F@bL@9k!%

%R!<%WFI$_=P$7$d%a%=%C%I8F$S=P$7;~$KI,MWHJ$k%"%I%l%9JQ49$N9bB.2=$O!$0JA0$N7k2L$rJQ49I=$KEPO?$7F*$/$3HKhj9T$&!%I,MW$HJkJQ49I=$O0J2<$N3DG$"$k!%

(1) %*%V%8%'%/%HJQ49I=!'%*%V%8%'%/%H%j%U%!%l%s%9$r8!:w%-!<$H$7!$3F%*%V%8%'%/%H$N@hF,%"%I%l%9$*hSB0@-$rJ];}$9$k!%

(2) %U%#!<%k%IJQ49I=!'%3%s%9%?%s%H!&%W!<%kXN%$%s%G%C%/%9$r8!:w%-!<H7!$3F%U%#!<%k%I$N%*%U%;%C%H$rJ];}$9$k!%

(3) %a%=%C%IJQ49I=!'%3%s%9%?%s%H!&%W!<%kXN%$%s%G%C%/%9$r8!:w%-!<H7!$3F%a%=%C%I$N@hF,%"%I%l%9$*$h$SB0@-$rJ];}9k!%

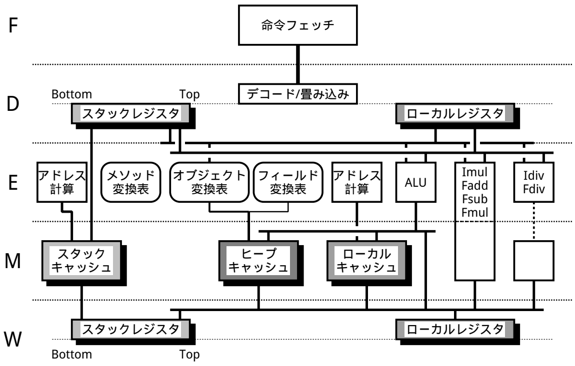
%m!<%+%kJQ?t>eNCMrD>@\;2>H9k$?$a$K!$9bB.%"%/%;%9$,2DG=$J%m!<%+%k%l%8%9%?$r@_$1!$%m!<%+%kJQ?t4V$N1i;;$r%l%8%9%?4V1i;;$H9k!%7+$7!$L58B8D$N%m!<%+%k%l%8%9%?$rMQ0U9k3HOG$-$J$$!%%l%8%9%?$K3JG<$G$-$J$$$bNO!$<g5-21$KJ];}9k!%<g5-21>e$N%m!<%+%kJQ?t$NCM$r;HMQ$7$F1i;;$r9T$&>l9g$K

L?Na$N<oN`	compress	jess	db	javac	mpegaudio	mtrt
%m!<%+%kJQ?tNFI_=P$7	32.5	37.3	40.5	35.4	32.8	33.4
%R!<%WNFI_=P$7	19.4	20.7	25.1	17.9	20.5	17.4
1i;;!$7?JQ49!$%9%?%C%/A`:n	15.9	1.8	6.8	6.3	16.5	8.4
>r7oJ,4t	6.1	10.9	8.1	9.3	3.3	3.6
Dj?t$N%W%C%7%e	7.2	5.6	1.3	5.3	12.8	5.8
%a%=%C%I8F$S=P$7	1.8	6.5	3.5	7.2	1.0	13.1
%a%=%C%I%j%?!<%s	1.8	6.3	3.5	6.1	0.9	13.1
%m!<%+%kJQ?tXN=q$-9~$_	9.1	5.4	6.9	4.5	6.3	1.7
%R!<%WXN=q$-9~$_	4.7	1.5	1.1	4.5	3.3	2.4
L5>r7oJ,4t	0.4	0.9	1.1	1.3	0.4	0.2
$=$NB>	1.0	3.0	1.9	2.2	2.2	0.7

I=**1** L?Na$N=P8=IQEY(C10L$O%)

$O!$$3liNCMr0lEYJ];}7F$*$/%l%8%9%?$,I,MW$HJk!%3N>l9gKO%*%Z%i%s%I!&%9%?%C%/$N%9%?%C%/%l%8%9%?$r2p7F<B9T$r9T$&!%%9%?%C%/%l%8%9%?$N?t$O!$B?$/Hb1 L?Na$,1 EY$K;H$&%9%?%C%/$N%(%s%H%j?t$@$1$"$l$PNI$$!%$^$?!$%m!<%+%kJQ?t$N<g5-21%"%/%;%9$N9bB.2=$K$O%m!<%+%k%-%c%C%7%e$rMQ0U9k!%F1MM$K!$%*%Z%i%s%I!&%9%?%C%/KBP7Fb9bB.2=N?$a%9%?%C%/%-%c%C%7%e$rMQ0U9k!%

>e$K=R$Y$?E@$r9MN8$KF~$l$F2>Dj$7$?%W%m%;%C%59=@.$r?^2$K<($9!%



?^**2** Java %W%m%;%C%5$N9=@.

3N%W%m%;%C%5$N%Q%$%W%i%$%s$OF,D,E,M,W $N5%9%F!<%8$+$i9=@.$5lF$$$k!%$^$?!$%m!<%+%kJQ?t$N$&$A!$%m!<%+%kJQ?tHV9f$N>.$5$$=g$K0lDj8D?t$r%l%8%9%?>e$KJ];}$9k3HKhj!$%*%Z%i%s%I!&%9%?%C%/$r2p5:$KD>@\%"%/%;%9$9k3H,2DG=HJCF$$$k!%5i$K!$%l%8%9%?$KBP1~IU$1ilJ+C?%m!<%+%kJQ?t$OM %9%F!<%8$N%m!<%+%k%-%c%C%7%e>e$KB8:_$7!$$=NCMrMQ$$$?1i;;$O%9%?%C%/%l%8%9%?$r2p7F9T$&!%%9%?%C%/%l%8%9%?$OD %9%F!<%8GFI_=P$9!%%*%Z%i%s%I%9%?%C%/$N%H%C%WKBP9$k%W%C%7%e/%]%C%W$KH<CFI,MWHJ$k!$%9%?%C%/!&%\%H%`$+$i%-%c%C%7%e$X$N%G!<%?B`Hr!$$*hS!$%-%c%C%7%e$+$i%9%?%C%/!&%\%H%`$X$N%G!<%?6!5k$O!I,MWK1~8F<+F0E*$K%W%m%;%C%5FbIt$G=hM}5l$k!%

%$%s%9%?%s%9JQ?t$N;2>H;~KO!$%3%s%9%?%s%H!&%W!<%k$X$N%$%s%G%C%/%9$,0[$JCF$bF1$8%U%#!<%k%I$r;2>H$7$F$$$k$H$$$&>l9g$,B8:_$9$k!%$3N?$a!$%F!<%V%k$rMQ$$$FJQ49$r9T$C$?8e$K%-%c%C%7%eXN%"%/%;%9$r9T$&3HKh$j!$0l4S@-$rJ]$D!%JQ49I=$OE %9%F!<%8!$%-%c%C%7%e$OM %9%F!<%8$K$*$$$F3F!9;2>H5l$k!%

%m!<%+%k%l%8%9%?>eNCM,99?7$5$lkKhK!$%-%c%C%7%e$X$N=q$-La7r9T$&$H<B9TB.EY$NDc2<$r$^$M$/!%$3lrHr1k$?$a!$%-%c%C%7%e$X$N=q$-La7O%a%=%C%I$N8F$S=P$7;~$K9T$&$3HH7?!%$^$?%a%=%C%I$+$i$N%j%?!<%s;~$K$O!$%-%c%C%7%e$KB`Hr$7$?%l%8%9%?$NCM$rI|85$9$k!%$3$NB>!$<B9T$9$k%a%=%C%I$r@Z$jBX$($k;~$K$O!$0z?t$*$h$SJV$jCM$N<u$1EO$7$r9T$&I,MW$,$"$k!%$3$NA`:n$K$O!$%9%?%C%/%l%8%9%?H%m!<%+%k%l%8%9%?$N4V$G$N%G!<%?$N0\F0$,I,MW$HJk!%$^$?!$%a%=%C%I8F$S=P$7!$%j%?!<%s;~KO!$%W%m%;%C%5$NFbIt>pJs$NB`Hr!$I|85$r9T$&I,MW$,$"$k!%

1i;;4o$O!$>h;;$*$h$SIbF0>.?tE@?t$N2C8:;;KD$$$F$O!$%G!<%?0MB8$,$"$k>l9g$K2%5%$%/%k$rMW9k%Q%$%W%i%$%sF0:n!$=|;;$O?t%5%$%/%k$rMW9kHs%Q%$%W%i%$%sF0:n$H2>Dj$7$?!%$3$l0J30$N1i;;$O!$1 %5%$%/%k$N%Q%$%W%i%$%sF0:n$r2>Dj$7$?!%G!<%?0MB8$Khk%Q%$%W%i%$%s%O%6!<%I$N:o8:$N$?$a!$3F%9%F!<%84V$K%G!<%?%P%$%Q%95!9=$rHw$($F$$$k!%

4.2 3F5!9=$N>\:Y

%W%m%0%i%`L>	4	8	16	!g
compress	30.7	37.8	41.6	41.6
jess	20.7	23.6	24.0	24.0
db	19.2	19.6	19.9	19.9
javac	22.6	26.4	26.4	26.4
mpegaudio	24.3	29.7	40.1	40.1
mtrt	24.6	25.9	25.9	25.9

I=**2** %l%8%9%??t$rJQ2=$5$;$?>l9g$KL?Na>v$_9~$_$KhC$F:o8:2DG=$JF0E*%9%F%C%W?t$N3d9g(C10L$O%)

?^2$N9=@.$G$O!$%m!<%+%k%l%8%9%?$K3JG<$G$-$k%m!<%+%kJQ?t$N?t$,!$L?Na>v$_9~$_$N8z2L$K1F6A$rM?$($k!%I=2$K%m!<%+%k%l%8%9%??t$rJQ2=5;$?>l9g$K!$L?Na>v$_9~$_$KhC$F:o8:2DG=$JF0E*%9%F%C%W?t$N3d9g$r<($9!%%l%8%9%??t$r8 H7$?>l9g$K!$%l%8%9%??t$rL5

8B$H2>Dj$7$?;~$H!$$[$\F1$88z2L$,F@$ilk3H$,$o $+$k!%

%W%m%0%i%`L>	%*%V%8%'%/%H JQ49I=	%U%#!<%k%I JQ49I=	%a%=%C%I JQ49I=
compress	2229	112	199
jess	80163	148	223
db	135977	111	208
javac	94920	167	267
mpegaudio	4477	223	226
mtrt	503672	128	225

I=**3** JQ49BP$rA4$FEPO?9kNKI,MW$J%(%s%H%j?t(C10L$O8D)

$^$?!$3FJQ49I=$N$&$A%U%#!<%k%IJQ49I=$*$h$S%a%=%C %IJQ49I=$O!$I=3$K<(9H$*$j!$9b!9300 DxEY$N%(%s %H%j?t$,$"lP==J,G"kNKBP7!$%*%V%8%'%/%HJQ 49I=$O!$6K$a$FB?$/$N%(%s%H%j$rI,MWH9$k!%$3$l $O!$%a%=%C%I$*$h$S%/%i%9$O@EE*$K?t$,7hDj5lkN KBP7!$%*%V%8%'%/%H$OF0E*$K?t$,7hDj5lk+iG $"$k$H9M$(il$k!%$3N3H+$i!$%W%m%;%C%5>eGO!$ %U%#!<%k%I$N%*%U%;%C%H$*hS%a%=%C%I$N%*%U%;%C%H $r5a$akK$O!$A4%(%s%H%j$r<}MF$G$-$k%O!<%I%&%'%" $rMQ0U$7!$JQ49BP$,JQ49I=KJ$$>l9g$N%l%$%F%s%7$O L5;k$G$-$k$H2>Dj$9$k!%

3lKBP7%*%V%8%'%/%HJQ49I=$O!$A4%(%s%H%j$rEP O?$9k@1N%O!<%I%&%'%"$rMQ0U$9k3H,Hs8=<BE* G"k?$a!$8=<BE*$J%(%s%H%j?t$H8z2LHN4X78$r C5$kI,MW$,$"$k!%$=3GJQ49I=$N%(%s%H%j?t$H!$JQ49 I=>e$K%*%V%8%'%/%H$N>pJs$,B8:_9k3d9g$rD4:`$7$? 7k2L!$4096 %(%s%H%jKBP7$F%R%C%HN($,Ls97.8% $H 100%$K$OF0$+J+C?!%3l$O%*%V%8%'%/%H$N<wL? $,C;$$$bN,B?$$$?aH9M$($ilk!%7+$70lHL$N RISC %W%m%;%C%5$N%m!<%I/%9%H%"L?Na$N=P8=IQEY$, 35!A50%$H8@ol$F$$$kNKBP$7!$I=1$K<($9h&$K JVM $N%R!<%W%"%/%;%9$NIQEY$ODc$$$?$a!$$3$N7k2L $O@-G=$K$=$l$[$IBg$-$J1F6A$rM?$(kbNGOJ$$$H 9M$($ilk!%

%W%m%0%i%`L>	16K	64K
compress	87.8	95.9
jess	85.8	91.1
db	79.2	82.8
javac	88.0	91.9
mpegaudio	95.1	97.0
mtrt	82.8	88.5

I=**4** %R!<%W%-%c%C%7%e$N%R%C%HN((C10L$O%)

%m!<%+%k%-%c%C%7%e$*$h$S%9%?%C%/%-%c%C%7%e$O!$;2 >H$5lkHO0O$,8=:_<B9TCf$N%a%=%C%I$G07$&bN$@$1 $K8BDj$5lk!%SPEC JVM 98 K*$$$F!$1 DN%a %=%C%I$r<B9TCf$K;2>H5l$k%m!<%+%kJQ?t$H%*%Z%i%s %I!&%9%?%C%/$N:GBg?t$O31 $*$h$S13 G"C?!%3N $?$a6I=j@-$,Hs>o$K9b$/!$%(%s%H%j?t$N>/$J$$%-%c%C %7%eGb%R%C%HN($O6K$a$F9b$$!%0lJ}!$%R!<%W%-%c%C %7%e$N9=@.$r%@%$%l%/%H%^%C%W!$%i%$%s%5%$%:$r64 %P %$%H$H2>Dj$7!$MFNL$,16K %P%$%H$H64K %P%$%H$N>l 9g$K$*$$$F!$%R%C%HN($rB,Dj7?7k2L$rI=4$K<($9!%

0J>eN3H+$i!$K\%W%m%;%C%5>eK*$$$F<g$K9MN8 9Y$-%Q%$%W%i%$%s%O%6!<%I$H7F!$1) %*%V%8%'%/ %HJQ49I=>e$K5aakCM$,B8:_$7J+C?>l9g2) %-%c%C %7%e$,%_%9%R%C%H7F<g5-21%"%/%;%9$r9T$&>l9g3)M %9%F!<%8$G@8;:7?CM$rE %9%F!<%8$G>CHq9k>l9g 4) %a%=%C%I$N8F$S=P7*hS%j%?!<%s!$$N4 DrHj $"$2k3HH9k!%

5. %G!<%?Ej5!$H%G!<%?:FMxMQ

5.1 %G!<%?Ej5!

%G!<%?Ej5!HO!$L?Na$N40N;rBT?$:$K$=$NL?Na$, =PNO$9$k7k2L$rM=B,$7!$M=B,CM$rMQ$$$F8eB3$NL?Na$N <B9T$r3+;O$9$k<jK!$G$"$k4)!%$?$@$7!$8e$+$iM=B,$5 l?%G!<%?$,@5$7$/$J$$$3H,H=L@7?;~$K!$M=B,$K 4p$E$$$FJQ99$7$?%a%b%j$N>uBV$rLa$9I,MW$,$"$j!$M= B,$r9TC?;~E@GN%a%b%j$N>uBV$rJ]B8$7$F$*$/5!9= $,I,MW$HJk!%

K\9FGO!$%9!<%Q%9%+%i<B9T$r2>Dj$;$:!$$^$:$O?^ 2$N9=@.$NHO0OFbK*1k%G!<%?Ej5!$N8z2L$K$D$$$F D4:`7?!%3N$?$a!$%G!<%?Ej5!$Khj9bB.2=$,2DG= JN$O!$%Q%$%W%i%$%s%O%6!<%I$,H/@8$9$k>l9gKD$$ FN$_$G$"$k!%6qBNE*KO!$%m!<%+%kJQ?t$NFI$_=P$7 N&$A%-%c%C%7%e$X$N%"%/%;%9$rH<$&$b$N!$%R!<%W$r ;2>H$9$kL?Na!$@0?t>h;;!$IbF0>.?tE@?t1i;;$N$&$A!$ <B:]$K%Q%$%W%i%$%s%O%6!<%I$N860xHJkbNG$"$k!% 3liNL?Na$O!$M %9%F!<%8K*$$$FCM$r@8;:$9k? aK!$<!$NL?Na$NE %9%F!<%8$K$*$$$FCMrI,MWH$9 $k>l9g$K$O!$%Q%$%W%i%$%s%O%6!<%I$,@8$8$k!%$^$?!$ %-%c%C%7%eXN%"%/%;%9$rH<$&%m!<%+%kJQ?tNFI_=P 7*hS%R!<%WNFI_=P7O!$<g5-21%"%/%;%9$,I,MW HJ$k>l9g$K$O!$<!$NL?Na$K$*$$$FE %9%F!<%8GCMr ;HMQ7J$$>l9gGb!$%Q%$%W%i%$%s%O%6!<%I$N860x$H Jj$&$k!%7+$7!$%m!<%+%kJQ?tNFI_=P7K4X7F $O!$%-%c%C%7%e$N%R%C%HN($,==J,$K9b$$$N$G!$%-%c%C %7%e%_%9$N>l9g$O%G!<%?Ej5!$NBP>]$HO7$J$$!%$^$?!$ %R!<%W%"%/%;%9;~KI,MWHJk%*%V%8%'%/%HJQ49I=$N ;2>H$K$*$$$F!$5a$akCM,JQ49I=>e$KB8:_$7$J$$>l9g K*$$$F$b%Q%$%W%i%$%s%O%6!<%I$,@8$8$k$?$a!$%G!< %?Ej5!$NBP>]H9$k!%

$^$?%G!<%?$NM=B,$N<jK!KO!$$:G$b4JC1$J5!9=G" $k Last Value Prediction4)$r2>Dj$7$F$$$k!%3N<j K!$GM=B,$5lkCM$O!$A02s$=$NL?Na$,@8;:$7$?CM$HF1 $8CM$G$"$k!%

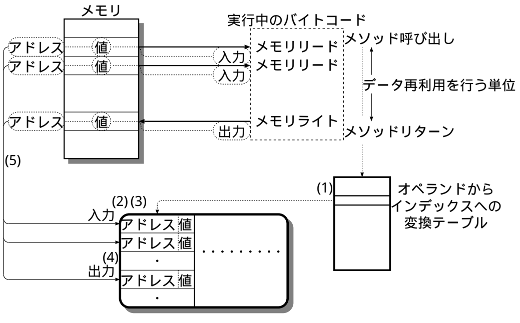
5.2 %G!<%?:FMxMQ

%G!<%?:FMxMQHO!$<B9T7k2L$rJ]B8$7$F$*$-!$:FEY F1$8F~NO%G!<%?$rMQ$$$F<B9T9k>l9g$K!$<B9T7k2L$r

:FMxMQ9k3HKh$j<B9T$r>JN,$79bB.2=$9$k<jK!$G$"$k5)6)!%G!<%?:FMxMQ$O%G!<%?Ej5!$H$O0[$J$j!$:FMxMQ9kCM$OI,$:@5$7$$$bNGJ1lPJi$J$$!%;HMQ9kCM$,M-8z$G$"$k$+$NH=CG$r!$%G!<%?Ej5!GO;HMQ8e$K9T$&NKBP7F!$%G!<%?:FMxMQ$G$O;HMQA0$K9T$&!%

%G!<%?:FMxMQK*$$$F$O!$F~NO%G!<%?$,@5$7$$$+I&$+$NH=CG$r9T$&$?$a$K!$$I$NL?Na$+iI$NL?Na$^GrC10LH7$F:FMxMQ$rE,MQ9kN+$r7hDj$9kI,MW,$"$k!%%G!<%?:FMxMQ$NC10L$H7F$O!$%a%=%C%IFb$NJ#?t$NL?NaNs$rC10L$H9kJ}K!$H!$%a%=%C%I$rC10L$H9kJ}K!$,9M$(il$k!%%a%=%C%IFb$NL?NaNs$rC10L$H9k>l9gKO!$L?Na$r%9%-%C%W9k:]$K%Q%$%W%i%$%s%O%6!<%I$,@8$8$k!%3N$?$a%9%-%C%W9kL?Na?t$,>/$J$$>l9gKO8z2L$,F@$ilJ$$!%0lJ}!$%a%=%C%I$rC10LH9$k>l9g$K$O!$%a%=%C%I$N8F$S=P7*hS%j%?!<%sKHbJ$&%Q%$%W%i%$%s%O%6!<%I$r:o8:9k3H$,2DG=$KJk!%$=$3$GK\9F$G$O!$%a%=%C%I$N8F$S=P7H9k3HK7$?!%

%a%=%C%I$rC10L$H7F%G!<%?:FMxMQ$r9T$&>l9g!$:FMxMQ$,2DG=$+H]$+$NH=CG$O!$%a%=%C%I$,8F$S=P$5lF$+$i%j%?!<%s9k$^$G$K9T$C$?%j!<%IA4$FKD$$$F!$$;2>H7?%"%I%l%9HCM,0JA0<B9T7?>l9g$HF1$8G"k+H]$+$rD4Yk3HKh$j9T$&!%$^$?%G!<%?:FMxMQ$,2DG=$G$"$k>l9gKO!$8F$S=P7+$i%j%?!<%s$^GK9Tol$?A4$F$N%a%b%j%i%$%H$r0JA0$HF1MM$K<B9T$9$k!%?^3$K!$%G!<%?:FMxMQ$N$?$a$KJ];}$9$k>pJs$r<($9!%



?^3 %G!<%?:FMxMQKI,MWJ%G!<%?

6. B,Dj>r7o$*$h$S7k2L

I>2AKOSPEC JVM 98 1)$rMQ$$$?!%3N%Y%s%A%^!<%/KO!$s1, s10, s100 $H3CJ3,$N<B9T%5%$%:$NL\0B$,B8:_$9k,!$C1=c$K10G\!$100G\$GOJ$$$?$a!$7k2LKb$=$NlF6A$,8=$olF$$$k!%$^$?!B,DjK$OKaffe$rMQ$$$?!%Kaffe>eGOSPEC JVM 98$Njack$,F0:n7J$+$C$?$?$a!$I>2A$NBP>]$+$i30$7$?!%

$^$:!$%W%m%0%i%`%5%$%:Kh$KL?Na>v$_9~$_$KhC$F:o8:$9k3H,G-$?F0E*%9%F%C%W?t$N3d9g$rI=5$K<($9!%

<!$K%G!<%?Ej5!$N8z2LKD$$$F<($9!%G!<%?Ej5!$NBP>]H7$?L?Na$O!$M%9%F!<%8$K$*$$$F%G!<%?$r@8;:$9$kL?Na$N$&$A!$<!L?Na$NE%9%F!<%8K*$$$F$=$NCM$r;HMQ$9$kL?Na!$%R!<%W%-%c%C%7%e>e$K5a$akCM,B8:_7J$+$C$?%R!<%W"%/%;%9L?Na!$%*%V%8%'%/%HJQ49I=>e$K5a$akCM,B8:_7J$+$C$?%R!<%W"%/%;%9L?Na$G$"$k!%%Q%$%W%i%$%s%O%6!<%I$O!$:#2s%G!<%?Ej5!$NBP>]$H7?L?NaN_$GH/@8$9kbNH9k!%$=$l0J30$N%a%=%C%I8F$S=P7d%a%b%j4IM}JI$NL?Na$K$O%Q%$%W%i%$%s%O%6!<%I$,@8$8$J$$$H2>Dj9k!%%R!<%W%-%c%C%7%e$N%_%9%R%C%H$N%Z%J%k%F%#!$$*hS!$%*%V%8%'%/%HJQ49I=$N%_%9%R%C%H$N%Z%J%k%F%#$OHb$K20%5%$%/%k$H2>Dj$7!$C1@:EY=|;;$N<B9T;~$K@8$8$k%Q%$%W%i%$%s%O%6!<%I$O16%5%$%/%k!$G\@:EY=|;;$N<B9T;~$K@8$8$k%Q%$%W%i%$%s%O%6!<%I$O30%5%$%/%k$H2>Dj$9$k!%$^$?!$M=B,$,30$l$?;~$N%Z%J%k%F%#$O0$H2>Dj9k!%3liN2>DjNbHG!$%G!<%?Ej5!$Khj:o8:9k3H$,$G$-$?F0E*%9%F%C%W?t$rI=6$K<($9!%$3$N7k2L$Khk$H!$%G!<%?Ej5!$N<jK!$Khj18.4%!A32.3%$N%5%$%/%k$r:o8:$9k3H,2DG=G"$k!%

:G8e$K%G!<%?:FMxMQ$N8z2L$r<($9!%%G!<%?:FMxMQ;~$N%a%=%C%I8F$S=P7N>JN,$N8z2L$rCNk?aK!$$3$3$G%a%=%C%I8F$S=P$7$*$h$S%j%?!<%s$KMW9k%5%$%/%k?t$r2>Dj9k!%%a%=%C%I8F$S=P$7!$%j%?!<%s;~$K9Tol$kFbIt>uBV%l%8%9%?$NB`Hr$*$h$SI|85$K$O10%5%$%/%k$rMW$9$k$b$N$H$9$k!%$^$?!$%m!<%+%k%l%8%9%?$N%5%$%:$O8$G$"$k$H$7!$%l%8%9%?1$D$K$D$-1%5%$%/%k$K$h$j>uBV$NB`Hr$*$h$SI|85$,2DG=G"kH9k!%3lir9g7W9k$H!$12s$N%a%=%C%I8F$S=P7*hS%j%?!<%sKMW9$k%5%$%/%k?tO=l>$l18$HJk!%$^$?!$%R!<%W$H$NHf3S$O%a%=%C%I8F$S=P$7$K@hN)$CFO9To:!$%a%=%C%I8F$S=P7H%*!<%P%i%C%W7F<B9T9kbNH7!$1%5%$%/%kKD-1D$N%R!<%W>e$NCMHNHf3S$,2DG=$G$"$k$H2>Dj$9$k!%$D$^$j!$%R!<%W>e$NCM$HHf3S$9$k2s?t$,A}2C9l$P!$%G!<%?:FMxMQ$N8z2L$O>/J/JkbNH9$k!%$3$N?tCM$rMQ$$!$$5iK!$%Q%$%W%i%$%s%O%6!<%I$,%a%=%C%I$N8F$S=P$7!$%j%?!<%s;~0J30$K0l@Z@8$8$J$$$bNH9M$($k$H!$I=7$K<($9h&$K!$1.0%$+$i47.1%$N%5%$%/%k$r:o8:$9k3H,2DG=G"$k!%

7. 9M ;!

%9%?%C%/%^%7%sOCMrA`:n9k$?$a$K!$0lC6%9%?%C%/$X%G!<%?$rJ#<L9k!%%9%?%C%/%^%7%sN3$NFCD'$O!$<B9T$9$kL?Na?t$NA}2CKDJ,kbNG$"$k!%L?Na>v$_9~$_$N<jK!$O!$$3$NFCD'$K4pE/L?Na?t$NA}2C$rM^$($kbNG"$k!%D4::$N7k2L$b!$<B:]$K8z2L$,$"$k3H$rN"IU$1$F$$$k!%$^$?!$L?Na>v$_9~$_$N<jK!$O!$B>$N<jK!$HNAH_9go;K*$$$F$bLdBj$J$/E,MQ$G$-$kbNG"$k!%

%5%$%:	compress	jess	db	javac	mpegaudio	mtrt
s1	41.6	24.0	19.9	26.4	40.1	25.9
s10	41.8	31.3	20.2	27.8	40.3	25.1
s100	42.0	29.6	22.3	27.6	40.3	23.4

I=**5** L?Na>v$_9~$_Kh$j:o8:2DG=$JF0E*%9%F%C%W?t$N3d9g(C10L$O%)

%5%$%:	compress	jess	db	javac	mpegaudio	mtrt
s1	32.3	18.7	19.7	18.6	28.3	18.4
s10	—	—	—	—	—	—
s100	—	—	—	—	—	—

I=**6** %G!<%?Ej5!Kh$j:o8:2DG=$JF0E*%9%F%C%W?t$N3d9g(C10L$O%)

%5%$%:	compress	jess	db	javac	mpegaudio	mtrt
s1	11.1	26.5	10.8	4.70	10.4	47.1
s10	7.89	44.9	14.3	15.0	7.58	1.10
s100	12.0	44.3	14.3	16.8	10.1	0.979

I=**7** %G!<%?:FMxMQKh$j:o8:2DG=$JF0E*%9%F%C%W?t$N3d9g(C10L$O%)

%G!<%?Ej5!$N<jK!$O!$M=B,$,@5$7$/J+C?>l9g$K!$ %a%b%j$N>uBV$rM=B,$r9T$C$?;~E@$N>uBVK^GLa95! 9=$,I,MW$HJk$?$a$KJ#;($J%O!<%I%&%'%"$,I,MW$H$J $k!%$3N?$a9b$$8z2L$rF@$ilk8+9~$_$,J1$1$P<B :]$K:NMQ$9k3HOFq$7$$$!%

%G!<%?:FMxMQ$N<jK!$O!$%Y%s%A%^!<%/$4HK7k2L$K PiD-$,B8:_9k!%$3lO!$%Y%s%A%^!<%/%W%m%0%i %`$N%=!<%9%3!<%I$N5-=RJ}K!KBg-$/M3Mh7F$$$k$H 9M$($F$$$k!%B>$N%*%V%8%'%/%H$NFbIt$JQ?t$rD>@\;2>H 7?$j!$C1=c$J%G!<%?9=B$$G$"$k$?$a$K%/%i%9$H7F Dj5A7J$$!$$JIN5-=R$r9T$&$H!$:#2s:NMQ7?J}?K GN%G!<%?:FMxMQ$,Fq$7$/$J$k!%$7$+$7!$$3Nh$&$J 5-=R$NJ}K!$O%*%V%8%'%/%H;X8~$r0U<1$7$?%W%m%0%i%_ %s%0$GOJ$/!$Java $r;HMQ$9$kL\E*$K9gC?bNHO 8@$$$Fq$$!%%*%V%8%'%/%H;X8~$r0U<1$7$F%W%m%0%i%`$N 5-=R$r9T$&>l9g$K!$K\%W%m%;%C%5$*$h$S%G!<%?:FMxMQ $N<jK!$Ohj9b$$@-G=$rH/4x$9kH9M$($F$$$k!%

%G!<%?Ej5!$H%G!<%?:FMxMQ$N<jK!$rF1;~$KE,MQ9k 3H$OIT2DG=$G$"$k!%%G!<%?Ej5!$rMQ$$$k$H!$$"$k;~ E@$G$N@5$7$$%a%b%jNCMrCNk3H,IT2DG=HJk? $a!$%G!<%?:FMxMQ$,2DG=$G$"$k$+$I$&$+$NH=CG$,G- $J$$$+iG$"$k!%3N2 DN<jK!$r!$B,Dj7k2Lrb$H $KHf3S$9kH!$%G!<%?:FMxMQ$O%G!<%?Ej5!hj$b8z2L E*$G$"$k$H9M$(ilk,!$$=$N8z2L$KOJPj$,$"$j!$ $`$7$m!$Java $NL\E*$K1h$C$?%W%m%0%i%`$G$"$k$[$I hj9b$$8z2L$,F@$ilk$H9M$($F$$$k!%

8. $^ $H $a

K\9FGO!$%P%$%H%3!<%I$NL?Na=P8=IQEY$*hS%9 %?%C%/%^%7%s$NFCD'$rbH$K!$9bB.2=$N<jK!$K$D$$$F 8!F$$r9TC?!%FC$K!$L?Na>v$_9~$_$*$h$SJQ49I=$N5! 9=$rF3F~$7$?%W%m%;%C%5$N9=@.$r2>Dj$7$?!%$=$N>e$G %G!<%?Ej5!$*$h$S%G!<%?:FMxMQ$r9TC?7k2L!$$=l> lNJ}<0$NFCD'$K1~8?8z2L$,$"k3H,H=L@7?!% %G!<%?:FMxMQ$N<jK!$O%G!<%?Ej5!hj$b8z2LE*$G$"$k $H9M$(ilkbNN!$$=$N8z2L$KOJPj$,8+$il?!% :#8e$O!$%-%&%C%7%e$N8z2L$NB,Dj$*$h$S!$L?Na$NH/9T B?=EEY$NA}2CKh$k%G!<%?Ej5!<jK!$N@-G=8~>e!$B>$N J}<0$ND4::!$$=li$r4^$a$?9bB.2=$NJ}<0NAH_9g$o $;$K$D$$$F8&5fr9$9$a$F$$$/I,MW$,$"$k!%

<U<- K\8&5f$K8f6(NO$$$?$@$-$^$7$?%*% `%m%s3t<0 2q<R$N5\ED;a$*$h$S:bCDK!?M5~ET9bEY5;=Q8&5f=j$N?@ 86;a$K46<U7^$9!%

;2 9M J8 8%

1) SPEC JVM 98 VERSION 1.03, the Standard Performance Evaluation Corporation, (1998).

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